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THE BASIC MASSIVE ROCKS OF THE LAKE SUPERIOR REGION.

Introduction. — Before the application of the microscope as a geological instrument the classification of rocks was dependent largely upon their apparent similarities and dissimilarities as noted by the unaided eye. When the use of this instrument became almost universal it was found that many rock types similar macroscopically were very different from each other in microscopic appearance, and very dissimilar genetically, while many of the apparently dissimilar types were discovered to owe their differences in appearance simply to the ordinary processes of weathering, which masked their original essential characteristics with the products of mineral alteration.

The rocks now known as gabbro are quite well characterized by peculiarities that are strikingly uniform in their essential features, though formerly the term was made to cover a large number of closely related but quite different rock types. Their history affords a good illustration of the manner in which rock classification developed from its early independent form to its present highly differentiated but well defined one.

In the case of the gabbros, as well as in the case of other rock groups, there were at first included under one name all rocks whose superficial features were similar to those of the type originally described. Later, more discriminating study separated this group into a large number of subordinate groups, based on

slight differences noted in the characteristics of their components. The number of such groups became larger and larger until eventually there were almost as many sub-groups recognized as there were students who had investigated them. Thus the classification grew complicated, because the criteria upon which it was based were mainly unessential, though prominent, peculiarities in the components comprising the classified bodies. The next step, following the use of the microscope in rock investigation, consisted in the consolidation of several sub-groups into one larger group—a result due directly to the comparative ease with which the microscope enables the student to distinguish between the primary and secondary—the essential and unessential—properties of rocks. After careful work of this kind had finally established the various varieties on the basis of mineralogical composition, attention was directed to the manner in which the rock components are associated—to the rock structure—and an explanation of variation in structure was sought in the environment of rock masses. The study of the gabbros thus became a geological study rather than a mineralogical one.

The brief historical sketch of the classification of the granular basic rocks, with special reference to the differentiation of the gabbros from the remainder of the group, will thus serve to illustrate the successive steps with which rock classification in general has progressed. But the sketch is not offered here solely as an illustration of the development of rock classification. It was originally written with a view of emphasizing the distinctive differences between the gabbros and the coarse diabases. In the Lake Superior region there exist many coarse basic rocks that have been called indiscriminately "gabbros." Some of these possess the features of true gabbros, as defined by a study of the history of this group of rocks, and others the peculiarities of diabases. Until the distinction between these two types is clearly recognized, it will be impossible to discuss the causes of their differences. It is hoped that the present contribution will serve partly to clear the ground for a careful study of the coarse basic eruptive rocks of the Lake Superior

province, which the writer desires to make as opportunities and time permit. The present plan proposes a series of papers appearing in this Journal at irregular intervals. The first follows this introduction. The second will embrace a sketch of previous work on the basic rocks of the region, and the succeeding ones will treat of the gabbros and coarse diabases in the Huronian and Keweenawan areas on both sides of the lake.

I. BRIEF HISTORY OF THE CLASSIFICATION OF THE GABBROS AND NEARLY RELATED ROCKS.

At about the same time the names Euphotide and Gabbro were applied, respectively by Haüy[1] in France and von Buch[2] in Germany, to rocks composed essentially of a foliated augite and a "compact feldspar." Haüy describes the Euphotides as consisting of a compact feldspar and diallage, for which combination he constructed the name from the two Greek words εὖ (blessed) and φῶς (light), in allusion to the green and white mottling in the hand-specimens from many localities. Von Buch's name, gabbro, was adopted from the Florentines[3] to cover a group of rocks that had been described at various times under a great number of different names, of which perhaps jade was the most common. Although gabbro was used by the Italians to designate what is now known as a diallagic serpentine, it has been accepted by nearly all geologists outside of France as the name to be applied to the group of rocks which von Buch so clearly and definitely separated from other allied rocks, and defined as made up of jade, feldspar and smaragdite.

Between the time of the appearance of von Buch's paper and the publication of the first microscopic description of gabbros by Rose in 1867,[4] many descriptions of these rocks appeared in

[1] Traité de Mineralogie, 2d Ed., IV., p. 535.

[2] Ueber den Gabbro, mit einigen Bemerkungen über den Begriff einer Gebirgsart. Geol. natur. f. Freund. zu Berlin, Mag. etc., 1810, IV., p. 128; 1816, VII., p. 234.

[3] Cf. T. S. HUNT: Contributions to the History of Euphotide and Saussurite. Am. Jour. Sci., 2d Series, Vol. XXVII., 1859, p. 336.

[4] G. ROSE.—Ueber die Gabbroformation von Neurode in Schlesien. Erster Theil. Zeits. d. deuts. Geol. Ges. XIX., 1867, p. 270.

the various geological journals. In 1835 Gustav Rose[1] separated the rocks composed of labradorite and hypersthene, with accessory olivine, mica, apatite and ilmenite, from the gabbros, and included them under the name "Hypersthenfels," at the same time suggesting that the term gabbro be confined to rocks containing labradorite and diallage. Many rocks were described as hypersthenites or hypersthene rocks, because of the supposition that the highly foliated augite in them really belonged to this variety of pyroxene. Delesse[2] and others showed that the compact feldspar of Haüy, and the jade mentioned by von Buch as an essential constituent of gabbros (afterwards called saussurite by de Saussure Jr., and by Beudant) is in some cases a true plagioclase; and Hunt[3] showed that in other cases it consists of zoisite, of white garnet mixed with serpentine, or of meionite, and that the rocks containing these substances usually also contain hornblende, with the characteristics of Rose's uralite. Hunt, further, declines to regard the rocks containing a triclinic feldspar and pyroxene (either augite, hypersthene or diallage) as true gabbros. He places them among the dolerites, and declares that the true euphotides described by Haüy and de Saussure are mixtures of *smaragdite* and saussurite; a declaration that Cocchi[4] made for the Tuscan rocks a few years later. Rocks composed essentially of diallage and saussurite Cocchi called granitones. Whatever may be the virtue of the objections raised to the use of the name gabbro for plagioclase-diallage rocks, it still continued[5] to be applied to rocks thought to be of this composition, just as hypersthenfels or hypersthenite

[1] Ueber die Gebirgsarten, welche mit den Namen Grünstein und Grünsteinporphyr bezeichnet werden. Poggendorf's Annalen, XXXIV., 1835, p. 16.

[2] Recherches sur l' Euphotide. Bull. Soc. Géol. d. France, VI., 1848-49, p. 547.

[3] T. S. Hunt.—On Euphotide and Saussurite. Am. Jour. Sci., 2d Series, Vol. XXV., 1858, p. 437; and Contributions to the History of Euphotide and Saussurite. Ibid., XXVII., 1859, p. 326.

[4] I. Cocchi.—Description des roches ignées et sedimentaires de la Toscane dans leur succession géologique. Bull. Soc. Géol. d. France (2) XIII., 1856, p. 267.

[5] Cf. P. Keibel.—Analysen einiger Grünsteiner des Harzgebirges. Zeits. d. deutsch. geol. Ges. IX., 1857, p. 569.

was used to designate those in which hypersthene was supposed to occur.[1]

When Naumann[2] wrote the chapter on rocks for the second edition of his "Lehrbuch der Geognosie" he defined the gabbros as characterized by the possession of labradorite or saussurite and platy augite, and divided them into two varieties—the gabbros, consisting of labradorite or saussurite, diallage and smaragdite, and the hypersthenites, containing hypersthene as the pyroxenic constituent, and sometimes a little secondary hornblende. Naumann recognized the difficulty of distinguishing between the gabbros and the diabases, even at this early day, before it was known that augite could have imposed upon it a parting as the result of pressure, for he says "Diese Familie würde sich vielleicht mit der nächstfolgenden des Diabases vereinigen lassen" (p. 573); and again, in a foot-note to diabase "Wenn der feldspathige Bestandtheil der Gesteine dieser Familie wirklich in allen Fällen Labrador wäre, so würde es zweckmässig sein, die Familie des Gabbro mit ihr zu vereinigen" (p. 578). The norites described by Scheerer[3] and Esmark, were thought probably to belong with the gabbros, but their true relations to the group were not known.

A few years later Kjerulf[4] discussed the results reached by himself and other Norwegian geologists, and ended by dividing the Norwegian rocks of the gabbro type into gabbros and norites, the former consisting of labradorite, augite, hornblende, and the latter of labradorite and diallage.

[1] Von Rath: Geognostische Bemerkungen über das Berninagebirge (?) in Graubündten. Ib. IX., 1857, p. 246.

Rammelsberg: Bemerkungen über den Gabbro von der Baste (Radauthal im Harz). Ib. XI., 1859, p. 101.

Von Richthofen: Geognostische Bechreibung von Süd-Tyrol. 1860, p. 146.

[2] Lehrbuch der Geognosie. B. I. 1860, p. 573-577.

[3] Geognostisch-Mineralogische Skizzen, gesammelt auf eines Reise an der Südküste Norwegens. Neues Jahrb. f. Min., etc., 1862, p. 668.

[4] Zusammenstellung der bisherigen Ergebnisse der geologischen Untersuchung Norwegens. Neues Jahrb. f. Min., etc., 1862, p. 144.

The macroscopic examination of the rocks of this type continued to give rise to many different methods of classifying them, but the general tendency after this time seems to have been toward the union of the gabbros and the hypersthenites into one group. Von Cotta,[1] for instance, embraces the gabbros hypersthenites and norites under the single head "gabbro,"[2] and then divides this group into five sub-groups—gabbros (granitone of Cocchi and other Italians), with labradorite or saussurite and diallage, or saussurite and smaragdite (gabbro of Cocchi, Hunt and others); euphotides, equivalent to the saussuritized gabbros of later authors; norites of Scheerer, which are regarded as gabbros containing a soda-orthoclase and some quartz; hypersthenites, consisting of plagioclase and hypersthene, and finally, Monzoni-hypersthenites, afterwards discovered by de Lapparent[3] to belong to an entirely different group since they contain no hypersthene.

In the same year in which von Cotta's classification appeared Aug. Streng[4] began the task of reducing the number of varieties that had been separated as distinct sub-groups of the general group gabbro. In his article on the gabbros and associated rocks in the Harz he describes the former as made up of labradorite, diallage, hypersthene, augite, hornblende, brown mica, and ilmenite. Of the hornblendic constituent he says, it is " Kein selbständiger Gementheil des Gabbro, und es werden daher durch ihre Anwesenheit keine besonderen Abänderungen erzielt." It is fibrous and is intergrown with the augite and diallage. The labradorite is saussuritized (p. 935) and the saussurite is therefore regarded as an unessential component. The hornblende-gabbros and the saussurite gabbros of the Harz

[1] Die Gesteinslehre. 2, Aufl. Freiberg, 1862.

[2] Cf. also Rocks Classified and Described. A Treatise on Lithology. By Bernhard von Cotta. An English edition by P. H. Lawrence, London, 1866.

[3] DE LAPPARENT: Sur la constitution géologiquè du Tyrol meridional. Annales des Mines. (6) VI., 1864, p. 259.

[4] AUG. STRENG: Ueber Gabbro und den sogenannten Schillerfels der Harzes. Neues Jahrb. F. Min., etc. 1862, p. 932.

are nothing but altered forms of the fresh gabbro. It is rather surprising to one accustomed to the use of the microscope as a means of studying rocks to learn that such correct conclusions as to the inner constitution of rock masses could be reached without the aid of this instrument as were reached by Streng in his study of these rocks.[1] A few years later the same geologist examined the gabbros and serpentines of Neurode in Silesia and discovered that all of the so-called hypersthene of these rocks is probably diallage, and that the serpentine rock, which from very early times had been known under the name of forellenstein, is really an altered gabbro, containing but a small amount of pyroxene. While Streng was examining the rocks of Silesia and deciding that the so-called hypersthenite is a true gabbro, Des Cloizeaux,[2] was investigating the hypersthenites and gabbros of France, with a view to their better classification. Des Cloizeaux declared as the result of his investigations that diallage, which is only a lamellar augite, and saussurite form euphotides and gabbros, and that many rocks that had been called hypersthenites or hyperites contain no hypersthene, but that the supposed hypersthene is diallage. He further proposes that distinctions between gabbros and hypersthenites be made more clear by the use of the name diallagite for labradorite and diallage rocks, and hyperite for those composed of labrodorite and hypersthene or bronzite. Although the use of Des Cloizeaux's name diallagite was not accepted by petrographers, all workers acknowledged the correctness of the statement that very many of the hypersthenites described from various localities are nothing more than gabbro in which the cleavage of the diallage is well marked.

Thus far the study of the gabbros and related rocks had proceeded without the aid to be obtained from the microscope. Many rocks had been described as belonging to the gabbro-type,

[1] A. STRENG: Ueber den Serpentinfels und Gabbro von Neurode in Schlesien. Neues Jahrb. f. Min., etc., 1864, p. 257.

[2] ALF. DES CLOIZEAX: Sur les Classifications des roches dites hyperites et euphotides. Bull. Soc. Geol. d. Fr. XXI, 1864, p. 105.

as defined by von Buch, and these had been given distinct names in accordance with the usual custom of distinguishing between the different varieties of a rock containing different characteristic mineralogical components. The years between 1860 and 1862, perhaps, marked the height of the wave of differentiation. After this time the classification of the numerous varieties took the direction along which it was to be carried farther by microscopical methods. Some of the hornblende gabbros, the forellenstein, many of the hypersthenites and some of the norites had been shown to be altered or fresh forms of true gabbros. The characteristics of the components of the two groups of the gabbros and the hypersthenites had been fairly well determined, and the similarity between many of the gabbros and the diabases had been pointed out.

The best résumé of the state of knowledge at this time concerning the rocks under discussion is to be found in Zirkel's[1] "Lehrbuch," published a year before the microscope was brought into use for the purpose of studying these rocks. Zirkel collected the observations of the different workers and incorporated them along with his own in such a way as to give an excellent impression of the value of macroscopic rock determinations, when undertaken by competent observers and aided by chemical analyses. He distinguishes as gabbros those rocks containing labradorite and diallage, at the same time agreeing with Bischof[2] in the view that the latter mineral is merely a variety of augite. Saussurite he regards as sufficiently characteristic of some gabbros to warrant their separation from others. He likewise looked upon smaragdite, which was thought to be an intergrowth of augite and green hornblende, as an essential constituent of some gabbros, and these he separated from the diallage gabbros under the name of smaragdite gabbros. The hypersthenites are described at some length, with the appended statement that many hypersthenites are probably gabbros. The

[1] F. ZIRKEL: Lehrbuch der Petrographie. Bonn, 1866, p. 112.

[2] BISCHOF: Lehrbuch der chemischen und physkalischen Geologie. Bonn, 1864. 2 Aufl. II, p. 654.

norites of Scheerer are classed among the gabbros and the hypersthenites, and those of Esmark are said to belong partly with these and partly with the diorites.

In the year succeeding the appearance of Zirkel's book, as has been stated, Rose[1] made the first microscopical examination of gabbros that has been recorded. He found among the Silesian gabbros two varieties, one of which is black and contains olivine, and the other green and free from olivine. Tschermak[2] followed Rose with a description of some Austrian gabbros, and an announcement that many serpentines are altered gabbros, and that Streng's forellenstein is only an olivine gabbro. He concluded, further, that augite and diallage differ only in physical properties, and therefore that gabbro "ist eine Abtheilung des Diabas" (p. 168).

In the few years succeding Tschermak's paper several contributions of great importance were added to the literature of the gabbros. Zirkel[3] recognized olivine varieties of these rocks among the Tertiary formations on the islands off the west coast of Scotland, and succeeded in showing that the hypersthenites described by Macculloch from the island of Skye contain no hyphersthene. He further pointed out as important the fact that the plagioclase associated with diallage is rich in inclusions, while that associated with ordinary augite is free from them. In the same year Hagge[4] continued the work that had been so ably begun by DesCloizeaux in 1864. He made a careful microscopic examination of all the important gabbro and hyphersthenite occurrences recorded, and reached a result very similar to that of Des Cloizeaux. He found that very many of the rocks

[1] G. ROSE: Ueber die Gabbroformation von Neurode in Schlesien, Erster, Theil. Zeits. d. deutsch. geol. Gessel. XIX, 1867, p. 270.

[2] Die Porphyrgesteine Oesterreichs aus der mittleren geologischen Epoche. Wien, 1869.

[3] F. ZIRKEL: Geologische Skizzen von den Westküste Schottland. Zeits. d. deutsch. geol. Gessell. XXIII, 1871, pp. 58 and 92.

[4] R. HAGGE: Mikroskopische Untersuchungen uber Gabbro und verwandte Gesteine. Kiel, 1871.

heretofore described as containing hypersthene, have none of this mineral in their composition. He divided the gabbros into those containing olivine and those without this constituent, and from the latter separated a group which he called saussurite gabbros, recognizing at the same time, however, that saussurite is an alteration product of labradorite. He described it as consisting "of small crystal needles, prisms and grains, which are colorless or light-green, and are scattered irregularly in a ground mass with the appearance of a colorless glass, which often forms clear patches in the saussurite" (p. 52).

Six years after Rose's description of the Neurode gabbro, and seven years after the appearance of Zirkel's masterly classification of rocks based almost entirely upon their macroscopic properties, the latter geologist was enabled to issue a second volume containing a classification of rocks based on the microscopical characters. In this volume[1] he defines the gabbros as granitic in structure, and consisting principally of plagioclase and diallage, usually with the addition of olivine. The plagioclase is usually labradorite. It usually contains fluid inclusions and numerous little dark needles and prisms arranged in a definite order. The diallage is filled with small brown plates and the olivine is characterized by thousands of fantastically shaped hair-like bodies. The structure of genuine gabbros is described as coarsely or finely granular. They contain no porphyritic crystals and no unindividualized ground mass.

The group of hyphersthenites had by this time become almost depleted of its members. Most of the hyphersthenites had been found to be diallagites, in the sense of Des Cloizeaux, so that but four undoubted occurrences of this rock were left to be included by Zirkel in the group. On the other hand, the number of "forellensteins" had increased to such a degree that a group was formed of the same classificatory value as that of the hypersthenite group. These rocks were described as having the structure of gabbros, while at the same time they contain but

[1] F. ZIRKEL: Mikroscopische Beschaffenheit der Mineralien und Gesteine, Leipzig, 1873.

little diallage. Their separation from the gabbros and the hypersthenites seems to be upon mineralogical grounds solely; since emphasis is laid upon the fact that their feldspar is apparently anorthite. Of such great importance was the mineral constitution of rocks regarded at this time, that we find no statement made with respect to the similarity between many diabases and many gabbros. The facts pointed out by earlier investigators to the effect that augite and diallage are but slightly different varieties of the same mineral, had been overlooked, or had, at any rate, been regarded as of little importance, since these expressions of opinion had for the most part not been founded on the study of thin sections. The microscope was used principally for the determination of the nature of the constituents of rocks, and had therefore emphasized their mineralogical composition out of due proportion to its importance.

The influence of Zirkel's book upon geologists in all parts of Europe was soon felt in the increased number of purely petrographical papers published in the journals; and this increased interest soon manifested itself in studies that included more than a mere description of rock sections. Vogelsang[1] had, years before, shown that there were great possibilities in the new science of petrography, but in the flush of excitement over the discovery of an easy and exact method of rock analysis, these possibilities were left unexplored until geologists became quite well acquainted with the essential components of the most important rock types.

Soon after the composition of the important rock types became fixed, attention was turned more particularly to their structure. Professor Judd[2] examined the gabbros in the denuded cores of Tertiary volcanoes in Scotland, and found that while diallage is the prominent pyroxene of the lower portions of the

[1] H. VOGELSANG: Philosophie der Geologie und Mikroskopische Gesteinsstudien. Bonn. 1867.

[2] J. W. JUDD: The Secondary Rocks of Scotland. Second Paper. On the Ancient Volcanoes of the Highlands and the Relations of their Products to the Mesozoic Strata. Quart. Jour. Geol. Soc., XXX. 1874, p. 220.

masses, in their upper portions the diallage is replaced in large part by augite. Many other papers of importance were published, and in most of these the structure of the rocks described was more or less briefly alluded to. Wiik[1] announced the fact that many of the Finnish rocks classed by Zirkel among the hypersthenites are olivine-diabases and olivine gabbros, while Stelzner[2] filled the gap thus produced in this group by the discovery of a bronzite gabbro from the Monte Rosa district in the north of Italy. Vallee-Poussin and Renard[3] made a thorough examination of the plutonic rocks of Belgium and the eastern part of France, and discussed the composition and structure of some gabbros.

The result of these and other workers were collected and edited by Rosenbusch[4] in his well-known book on the microscopical characters of massive rocks, in which the fixing of rock types which had been begun by Zirkel was carried out in a scheme which was not improved upon until the same author published the second edition of his treatise ten years later[5]. In the scheme proposed in 1877, the gabbros were placed among the pre-Tertiary massive granular rocks. The group was made to include all pre-Tertiary rocks consisting essentially of diallage and plagioclase in their unaltered state, either with or without olivine. Saussurite was recognized as a secondary product produced by the alteration of plagioclase, and green hornblende (actinolite and smaragdite) as the result of an alteration of diallage. The saussurite and the hornblende gabbros were no longer

[1] F. J. Wiik: Mineralogiska och petaografiska meddelanden. Ref. Neues Jahrb. f. Min., etc., 1876, p. 206.

[2] A. Stelzner: Briefliche Mittheilung. Zeitz. d. d. geo. Gessell., XXVIII. 1876, p. 623.

[3] Ch. de la Vallee-Poussin, et A. Renard: Memoire sur les caracteres mineralogiques et stratigraphiques des roches dites plutoniennes de la Belgique et de l' Ardenne francaise. Bruxelles, 1876, pp. 62–76 and 125–128.

[4] H. Rosenbusch: Mikroskopische Beschaffenheit der Massigen Gesteine. Stuttgart, 1877.

[5] H. Rosenbusch: Mikroskopische Beschaffenheit der Massigen Gesteine. 2te Aufl. Stuttgart, 1887.

regarded as sub-groups of the gabbro family, but were looked upon merely as altered gabbros. Magnetite and titanic iron oxide as well as apatite were mentioned as accessory in all members of the group, and hornblende, rhombic pyroxene, brown mica and quartz were spoken of as occurring in many (p. 459). The difficulty of distinguishing between a gabbro and a diabase was clearly appreciated. The distinction between diallage and augite, upon which is based the mineralogical distinction between gabbro and diabase, is acknowledged to be of doubtful value for this purpose, since some rocks with the other properties of gabbros have an augite devoid of the diallagic parting, while others with many of the properties of diabase possess an augitic constituent with the parting highly developed. "Höchstens dürfen sie (the gabbros) als ein unterabtheilung der Diabase, welche sich durch eine eigenthümliche Structur und Theilbarkeit ihres Pyroxens charakterisirem." The structure of the gabbros was said to vary within narrow limits. They are always coarse-grained rocks whose different structures depend principally upon the different amounts of their constituents. Since they are so well characterized by the monotony of their texture, and since no gradations[1] between them and porphyritic or glassy forms were known, while on the other hand the structure of the diabases varies so widely between holocrystalline and glassy, the former were regarded as a distinct rock type. Rosenbusch, however, declined to regard the gabbros as dependent for their individuality upon the mere possession of an augite with pinacoidal parting, but was inclined to look upon them as rocks occupying a position in the scheme of classification intermediate between that of the diabases and that of the norites, the latter

[1] MR. T. T. GROOM has recently described a gabbro glass associated with gabbro at Carrock Hill in the Lake District, England, under the name carrockite. Since this glass occurs only as a narrow selvage where the gabbro has cooled rapidly in contact with preëxisting rocks, it cannot be considered as contradicting the above general statement. The structure is not one connected genetically with the rock itself, but is a local phenomenon dependent upon extraneous circumstances. See T. T. Groom: On the Occurrence of a new form of Tachylyte in Association with the Gabbro of Carrock Fell, in the Lake District. Geol. Magazine. Jan. 1859, p. 43.

consisting of plagioclase and an orthorhombic pyroxene, and therefore corresponding in part to Zirkel's hyphersthenites. The principal difference between the gabbros and diabase was, then, one of structure, while subordinate to this was a difference in mineralogical composition. In his sentences closing the discussion of the gabbros Rosenbusch writes: "Man müsste aber alsdann das Hauptgewicht für die Absonderung der Gabbros nicht auf den eigenthümlich struirten Diallag legen, sondern darauf, dass sie einen pinakoidal spaltbaren klinorhombischen Pyroxen als wesentlichen und daneben einen rhombischen Pyroxen als accessorischen Gemengtheil enthielten." The distinction here made is evidently a strained one, for quite a number of gabbros were known in which the structure is the typical gabbro structure, while at the same time they are entirely free from rhombic pyroxenes. The new group name "Norites" is borrowed from Esmark and Scheerer, although the rocks described by these geologists are by no means typical of the group. The advantage of the name over "hyphersthenite" is readily appreciated when it is remembered that the rhombic pyroxene of these rocks is not always hyphersthene.

The publication of Rosenbusch's classification of the massive rocks fixed the characteristics of the various types with some degree of scientific accuracy. There was, however, much to be learned concerning the less well known types, and much more to be discovered concerning the relations of the various types to each other.

The work of Judd, referred to above, was the beginning of a severe attack on the wavering line of geologists who still clung to the belief that mineralogical differences alone should determine the class to which a rock should be referred. It would be unprofitable in the present place to mention all of the important articles treating of gabbros and their varieties. It will be sufficient for our purposes to refer briefly only to those papers in which new types of gabbro are described and a little more fully to those which treat of the classification of these rocks.

The existence of true hyphersthenites (norites), of gabbros,

and of types intermediate between these, was established at the time that Rosenbusch's book appeared. In this year (1877) Törnebohm[1] suggested that the name hyperite be used for the latter classs, composed essentially of plagioclase, diallage and an orthorhombic pyroxene, that the term gabbro should be used to designate plutonic rocks in which the pyroxene is diallage, and that hyphersthenite (or norite) should be restricted to those containing a rhombic pyroxene as their principal augitic constituent. This suggestion has not met with a very wide acceptance because the gradation between the three types is very gradual, and in all cases the geological relations of the types are the same. It is convenient, however, as a descriptive name for those gabbros containing two pyroxenes.

In the same year Streng[2] investigated the crystalline rocks of Minnesota and described a gabbro from near Duluth, in that State, to which he gave the name hornblende-gabbro, because of the supposition that the brown hornblende it contains is primary. Irving,[3] however, has shown that much of the brown hornblende in the rocks of the Lake Superior region is secondary. He thought that nearly all, if not all, of the hornblende of the hornblende gabbros is of this nature. Williams[4] has also shown that compact brown hornblende is often a secondary product of the alteration of augite; and Wadsworth[5] holds to the view that this is the character of all the hornblende in the Lake Superior gabbros.

[1] A. E. Törneböhm: Ueber die wichtigsten Diabas und Gabbrogesteine Schweden. Neues Jahrb. f. Min., etc., 1877, p. 387.

[2] A. Streng and J. H. Kloos: Ueber die krystallinischen Gesteine von Minnesota in Nord Amerika. Neues Jahrb. f. Min., etc., 1877.

[3] R. D. Irving: On the Paramorphic Origin of the Hornblende of the Crystalline Rocks of the Northwestern States. Am. Jour. Sci., Vol. XXVI, 1883, p. 27; Ib. XXVII, 1884, p. 130.

[4] G. H. Williams: On the Paramorphosis of pyroxene to hornblende in Rocks. Am. Jour. Sci., XXVIII, 1884, p. 259.

[5] M. E. Wadsworth: Preliminary Description of the Peridotytes, Gabbros, Diabases and Andesytes of Minnesota. Bull. No. 2. Geol. and Nat. Hist. Surv. of Minn., St. Paul, 1887, p. 66.

If Irving, Williams, and Wadsworth are correct in their opinion, the hornblende-gabbro of Streng is merely an altered form of gabbro, and therefore it does not deserve a distinctive name (except for the mere purpose of description), any more than do the saussurite-gabbros.

Another type of gabbro to which a distinctive name has been given is also found in the region surrounding Lake Superior. This is an orthoclase-gabbro which has been carefully described by Professor Irving. An unstriated feldspar taken to be orthoclase had been discovered in gabbros from European localities by various petrographers, but it was usually present in such small quantity that but little importance was attached to it. In this country Pumpelly[1] and Julien[2] identified orthoclase in certain gabbros from Wisconsin, and Irving[3] discovered it in similar rocks from both Wisconsin and Minnesota. The latter author describes the orthoclase as often reddened and charged with secondary quartz. He mentions in detail the characteristics of the rocks containing it, and regards the differences noted between these and the non-orthoclastic gabbros as of sufficient importance to warrant their separation from the latter under the variety name orthoclase-gabbro.

Within the past few months still an additional gabbro variety has been brought into prominence by Adams[4] and by Lawson[5] working in different portions of North America. This consists essentially of plagioclase with gabbro characteristics, with which is associated only now and then a grain of pyroxene or magnetite. It differs from "forellenstein" in containing no olivine, and from

[1] R. PUMPELLY: Geology of Wisconsin, III, 1880, pp. 38, 40, 41.

[2] A. A. JULIEN: Microscopical Examination of eleven rocks from Ashland County, Wisconsin. Geol. of Wisconsin, III, 1880, p. 233.

[3] R. D. IRVING: The Copper-Bearing Rocks of Lake Superior. U. S. Geol. Survey, Monograph V, pp. 50–56.

[4] F. D. ADAMS: Ueber das Norian oder ober-Laurentian von Canada. Neues. Jahrb. f. Min., etc. B.B. VIII, p. 419.

[5] A. C. LAWSON: The Anorthosytes of the Minnesota Coast of Lake Superior. Geol. and Nat. Hist. Surv. of Minn. Bull. No. 8, p. 1.

gabbro proper in the absence of diallage and orthorhombic pyroxenes. To this variety belong the norite[1] of New York State, the labradorite rock of Labrador, and the "anorthite rock" of Irving[2] from the north shore of Lake Superior.

But if we are to regard the anorthosites as gabbros in which pyroxene and olivine are wanting, we must pass to the other end of the series and include in the gabbro group those rocks in which plagioclase is wanting, and in which the sole essential components are pyroxene and olivine, or the pyroxenes alone—the peridotites of most authors and the pyroxenites of Williams.[3] Judd[4] has shown conclusively that the peridotites of Scotland are but phases of the gabbro with which they are associated, consequently they may with good reason be included within the gabbro group. But other peridotites and many of the pyroxenites must be regarded as distinct rocks. They are the products of the cooling of magmas of an essentially different composition from that of the gabbros, hence their consideration may well be excluded from this history.

The varieties of gabbro that depend upon mineralogical com position, so far as known, have been carefully described and named by their investigators—the names referring for the most part to the nature of their iron-bearing constituents. These are gabbro and olivine-gabbro, hyperite, norite, peridotite and pyroxenite, together with the alteration products of the first named, viz.: hornblende, saussurite, orthoclase, and perhaps quartz-gabbro,[5] the latter of which is more properly a quartz norite, since it contains no diallage. The varieties whose names have reference to

[1] Cf. F. D. ADAMS: l. c., p. 475 and 483.

[2] R. D. IRVING: Copper-Bearing Rocks of Lake Superior. Mon. V. U. S. Geol. Survey, p. 438.

[3] G. H. WILLIAMS: The non-Feldspathic Intrusive Rocks of Maryland and the course of their Alteration. Amer. Geologist, VI, 1890, p. 95. Not the pyroxenites of the French authors, which are mainly augite gneisses or schistose gabbros.

[4] J. W. JUDD: On the Tertiary and older Peridotites of Scotland. Quar. Jour. Geol. Soc., XLI, 1885, p. 357.

[5] Cf. U. S. GRANT: Note on the Quartz-Bearing Gabbroin Maryland. Johns Hopkins Univ. Circ. No. 103.

the feldspathic component are the orthoclase-gabbro of Irving and the eukrites[1] of the older authors. The latter name was proposed to designate rocks whose feldspar is anorthite. It never received a very wide application owing partly to the difficulty of distinguishing positively anorthite from the other plagioclases. Since the discovery by Tschermak that the plagioclases form a series of isomorphous compounds, the value of the distinction recognized by the name has disappeared and the name itself has fallen into disuse.

In addition to these there are two other varieties that seem to be sufficiently well characterized to deserve special names. One of these, the anorthosite, consists exclusively of gabbroitic plagioclase and the other "forellenstein" contains olivine and plagioclase.

During the past few years nearly all the work on the gabbros has tended toward the separation of these rocks from the diabases by sharper lines than those based merely on mineralogical distinctions. All those who had attempted to separate the two groups by the methods in use had failed, and some had thought it well to include the two in one group. The views of the earlier petrographers on this subject have been referred to. Later petrographers have accorded with these in their recognition of the fact that the value of the pinacoidal parting of diallage is not of great importance for the purpose of rock classification. The discovery of Judd, referred to above, produced a marked effect on the work of those who followed him in the same field.

In 1883 J. Roth[2] declared that the position of the gabbros with respect to the diabases depends upon the signification given to diallage. If we regard it as an altered augite with a pinacoidal parting produced by twinning it is found, as Rosenbusch has already stated, that the parting may occur in the pyroxene of some rocks without the presence of

[1] For a discussion of the eukrites see J. ROTH: Allgemeine und Chemische Geology, II, 1883, p. 200.

[2] Allegemeine und Chemische Geologie, II, p. 185.

twinning lamellae. On the other hand, the pinacoidal parting is entirely absent in cases where twinning lamellae are present. Consequently not much dependence can be placed upon this constituent as a means of distinguishing between gabbros and diabases. The former rocks are evidently related to the latter, whose typically granular, holocrystalline forms they are. Irving,[1] in his work on the geology of the Keweenawan series in Michigan, Wisconsin, and Minnesota, was compelled to make use of coarseness of grain as a means of distinguishing between diabases and gabbros, both of which were thought by him to occur as flows. "It is evident," he writes, "that my observations on these north Wisconsin gabbros bear out the conclusions reached by certain European lithologists, as to the subordinate importance of the foliated condition of augite, by which gabbro is ordinarily separated from diabase, of which it would seem to be merely a phase. Nevertheless, the name is here retained, not only because most of our rock is very close to the typical European gabbros, but more especially because it is so sharply contrasted with the typical Keweenawan diabase that a separate name seems necessary." And again, when speaking of the diabases, he says,[2] "Although grading through coarser kinds into the coarse olivine-gabbros, the fine-grained rocks here considered deserve a place by themselves. The gradation into the coarser kinds has never been observed in any one bed, and they are very strongly marked by their external characteristics, both in the fresh and altered states."

The prime distinction between the two classes of rocks is, then, one based upon structure and not upon the difference between the augitic and diallagic nature of its pyroxenic constituent. The structure of the most typical gabbros was recognized by most geologists to be granitic and that of the diabases as ophitic. Professor Judd[3] proposed to restrict the name

[1] Geology of Wisconsin, III, 1880, p. 171.

[2] Copper-Bearing Rocks of Lake Superior, p. 69.

[3] J. W. JUDD: On the Tertiary and older Peridotites of Scotland. Quart. Jour. Geol. Soc., Vol. XLI, 1885, p. 354; and On the Gabbros, Dolerites and Basalts of Tertiary age in Scotland and Ireland. Ib. XLII, 1886, p. 49.

gabbro to granitic forms of plagioclase pyroxene rocks, and to designate as diabases the ophitic, porphyritic and glassy forms. He agrees with Zirkel[1] and Lasaulx[2] in regarding the Hebridean rocks as Tertiary in age, and at the same time as corresponding in all their characteristic features with older augite-plagioclase rocks of granitic structure. These rocks possess not only the structure of the most typical gabbros, but their various constituents are marked by the same microstructure. The plagioclase, olivine, and augite contain the numerous inclusions that were so early recognized as characteristic of these minerals in gabbro, and the latter mineral, the augite, is marked by the diallagic parting, which is the result of the action of a secondary process upon ordinary augite. The process, called by Professor Judd[3] schillerization, is moreover shown to be a function of the depth at which the original rock magma cooled, and the granitic structure of the rock mass is demonstrated to be likewise due to the fact that the rock possessing this structure crystallized at some depth below the earth's surface.

The work of Professor Judd established two great facts, viz.: first, that the age of a rock cannot serve as a basis for rock classification, since it has but little to do with the development of a characteristic structure; and, second, that the geological position of a rock mass is the condition determining not only its structure, but also the peculiar features possessed by its constituents. The rocks which it is proposed to call gabbros are marked by both of the characteristics of deep-seated rocks, while the diabases possess neither of them. The differences between the two groups of rocks, as expressed by their structures, are probably differences that are dependent upon the geological conditions under which they solidified.

[1] Zeits. d. deutsch. Geol. Gesell. XXIII, 1871, pp. 58 and 93.

[2] Min. u. Petrog. Mitth. I, 1878, p. 426.

[3] Cf. also J. W. JUDD: On the Relations between the Solution-planes of Crystals and those of Secondary Twinning; and on the Mode of Development of Negative Crystals along the former. A Contribution to the Theory of Schillerization. Mineralog. Magazine, VII, p. 81.

Professor Rosenbusch[1] clearly appreciated the value of the work on the basic rocks of the Hebrides, for, in the second edition of his Mikroskopische Physiographie, he defines the gabbros as hypidiomorphically granular *plutonic* rocks, consisting of a basic plagioclase, diallage, or a pyroxene resembling diallage, rhombic pyroxenes and often olivine. The important feature in this definition is the characterization of the gabbros as plutonic rocks. The diallage no longer defines the gabbro. The conditions which determined the characteristic structure of the rock at the same time produced the diallagic structure in its pyroxenic constituent. The structure of the typical gabbros, as defined by Rosenbusch, is granular, with the components all equidimensional. Notwithstanding the fact that some plutonic rocks of this class seem to lack the granitic structure, it remains true that the typical gabbro is well described by this definition.

When, however, we seek to separate the gabbros from the diabases we are met at the outset with the same difficulties that have always stood in the way of an exact separation of these two rocks. Rosenbusch[2] describes the diabases as possessing some of the features of plutonic rocks, while at the same time they possess other features that are eminently characteristic of rocks that have flowed out upon the surface of the earth. He nevertheless includes them with the plutonic rocks, stating, however, at the same time that they occur principally as dykes and interbedded flows; are more frequently interstratified with schists than are any other plutonic rocks; and that their predominant structure is the ophitic. That there is a fundamental difference between the two rocks is shown by the fact that the typicial gabbro can not be traced into porphyritic or hyprocrystalline varieties, nor is it ever accompanied by tufas. Whereas the diabases are often porphyritic, and are not infrequently associated with diabasic tufas. A consideration of these phenomena, together with the great differences in the structures of the typical gabbros and diabases, have led Loewinson-Lessing to regard the gabbros as

[1] Mikroskopische Physiographie, der Massigen Gesteine, 2, Auf. 1887, p. 132.

[2] Mikroskopische Physiographie, 2 Auf. II, pp. 174 and 195.

the intrusive[1] equivalents of the diabases, which he thinks were effusive under water, with the augite porphyrites as their equivalent terrestrial effusives. The conclusions of Loewinson-Lessing are not at all startling in their originality, for the wide separation in origin of the two groups of rocks here discussed has been suspected by petrographers ever since the classification of rock-types based on age, mineralogical composition and structure, gave way to the classification founded on geological relationships. The placing of the diabases with the effusive rocks will probably be looked upon with favor by all petrographers, especially since Professor Rosenbusch[2] has treated of them as members of this group in his Heidelberg Lectures, and Brauns[3] has shown that a typical lava flow of a suitable composition may have the diabasic structure developed in it but a few feet below its upper surface.

Lawson,[4] on the other hand, has shown conclusively that the coarse grained, ophitic diabases, interbedded with the Huronian slates and quartzites on the north shore of Lake Superior, are not effusive, but are intrusive, and that their intrusion between the fragmentals with which they are associated, must have occurred at a time when these were deeply buried under a great thickness of overlying rocks. Consequently these coarse, holocrystalline diabases must be regarded as intermediate in their geological relationships, as they are in their structural features between the hypidiomorphic, holocrystalline, plutonic gabbros, and the typically ophitic, hypocrystalline effusive diabases.

But if the hypocrystalline diabases are classed with the effusives, their position with respect to the melaphyres and basalts

[1] F. LOEWINSON-LESSING: Quelques considerations genetiques sur les diabases, les gabbros et les diorites. Bull. d. l. Soc. Belge. de Geol. etc., II, 1888, p. 82.

[2] Cf. Zeits. d. deutsch. geol. Ges. XLI, 1890, p. 533.

[3] R. BRAUNS: Mineralien und Gesteine unf dem hessischem Hinterland II, 3, Diabas mit geflossener Oberflache (Strick oder Gekroselave) von Quotshausen. Zeits. d. deutsch. geol. Ges. XLI, 1890, p. 491.

[4] A. C. LAWSON: The Laccolitic sills of the northwest coast of Lake Superior, Geol. and Nat. Hist. Surv. of Minn. Bull. No. 8, 1893, p. 24.

must be defined. Brauns,[1] in the article referred to in the last footnote, has attempted this correlation. He finds, after reviewing the opinions of various writers on the subject, that "It is not possible to distinguish between diabase and melaphyre on purely petrographical grounds, whether olivine is considered as an essential component of melaphyres, as Rosenbusch holds, or whether it is regarded as unessential in these rocks." In order to construct an exact definition for these three types of rock Brauns is compelled to fall back upon distinctions of age, although Rosenbusch[2] in his last article, in which he refers to this subject, declares it as his opinion that "it requires no great foresight to prophesy that in the not very distant future, this separation [of the effusive rocks into an older and a younger series] will be proven untenable." In spite of the almost certainty that Braun's classification will meet with but little favorable acceptance, it is given here in order to complete the sketch of the history of gabbros and the related rocks. According to Brauns, the basalts are made to include rocks of this class from recent time to the beginning of the Tertiary age. The limit of separation between the melaphyres and the diabases passes through the productive coal measures; rocks older than this are regarded as diabases, while the melaphyres extend from the Carboniferous to the Tertiary. Each group is divided into varieties, according to structure, and into sub-varieties according to mineralogical composition. A tabular grouping of the principal divisions of the effusive rocks of the composition of diabase follows:

	Paleozoic to Productive Coal Measures.	Mesozoic to Tertiary.	Tertiary to Recent.
Granular - - -	Diabase.	Melaphyre.	Basalt.
Porphyritic - -	Diabase-porphyrite.	Melaphyre-porphyrite.	Basalt-porphyrite.
Glassy - - - -	Diabase-glass.	Melaphyre-glass.	Basalt-glass.

It is very evident that the introduction of the diabases among

[1] R. BRAUNS: Ib. 5. Systematik der Diabas, Melaphyr und Basaltgesteine. Ib. p. 532.

[2] H. ROSENBUSCH: Ueber die chemische Beziehungen der Eruptivgesteine. Min. u. Petrog. Mitth. XI, 1890, p. 146.

the effusive rocks has created a disturbance in the melaphyre-basalt group that can only be quieted by the ejection of one of the members of the group, probably the melaphyres, from the position it now occupies. When this is done it is probable that the diabases will take the position thus left vacant, and the plagioclase-augite rocks will be found to occupy these places with respect to each other: the gabbros, the position of a deep seated rock, the diabases that of the corresponding holocrystalline effusive, and the basalt that of the hypocrystalline equivalent.

W. S. Bayley.

Waterville, Me., June 1, 1893.

NOTES ON THE STATE EXHIBITS IN THE MINES AND MINING BUILDING AT THE WORLD'S COLUMBIAN EXPOSITION, CHICAGO.

THE Mines and Mining Building at the World's Columbian Exposition contains exhibits of the different mining industries of the various states of the United States and of foreign countries, exhibits of many of the manufactured products derived from these industries, exhibits of various kinds of mining and engineering machinery, and many private mineralogical and petrographical collections of great value and interest. To describe the whole would require a volume, and it is the intention of the present paper to discuss only some of the more important features of the state exhibits, with occasional references to the foreign exhibits.

A mining exhibit should seek to show the actual resources of the region it represents, whether these resources be developed or undeveloped, and to give the different products prominence according to their present or prospective importance to the region. The products of present importance should be exhibited as showing what the region actually produces; the products of prospective importance should be exhibited as showing what the region contains in bountiful quantities, but what is not yet utilized, either from lack of knowledge on the part of the public concerning it, from temporary inaccessibility, or from some other cause. By this means many valuable materials, which have not yet been developed, are brought to the attention of the general public, and often to that of specialists on such subjects, and in this way receive quicker development than if they had not been exhibited. It is often difficult to give the proper relative importance in an exhibit to products actually being mined and those which have not yet been devel-

oped, but an effort can be made in this direction, and it is always possible to state that a given material is not being mined.

A properly arranged mining exhibit affords advantage in two directions. In the first place, it benefits the exhibitor in calling attention to his products, and in the second place it is of great educational benefit to the general public as showing what different regions produce. The best interests of the exhibitor are served by a true exhibition of his products; while the educational value of an exhibit depends almost entirely on the exactness with which the exhibit reproduces the actual state of affairs, for if the exhibit is exaggerated in one direction or neglected in another it leaves with the uninitiated a false idea of the resources of the region.

Most of the state exhibits have been collected and arranged by commissioners appointed by the state, and are supposed to fully represent the resources of the state. Many of the foreign exhibits, however, are made up of the individual exhibits of different mining companies, and often show only a certain class of the products of a given region. They are, therefore, not claimed to always represent the whole of the mining industries of a region[1] and cannot be criticised for not doing so. The state exhibits, however, should fairly and honestly represent the mining industry within their borders, giving undue prominence to no one product, and neglecting nothing that should be represented. In this feature some of the states have been highly successful, while others have done worse than make a failure, for they have misled those who are not sufficiently acquainted with the resources of the country to know that the exhibit is not characteristic. Some of the states have exhibited and made very prominent great amounts of materials which they do not possess in paying quantities; other states have actually exhibited materials which they do not possess at all, and which have been obtained from other states, a proceeding which is very misleading to the general public.

[1] A notable exception to this is the New South Wales exhibit, which is one of the best in the building.

It has been the object of Mr. F. J. V. Skiff, Chief of the Mines and Mining Building, to make the mining exhibit truly characteristic of the states and foreign countries represented, and thus to give it the greatest possible value to the general public and to the individual exhibitors. His supervision has been wise and systematic, and it is to him that a large part of the success of the mining exhibit is due. Where failures have been made they have been the fault, not of the Chief of the Mines and Mining Building, but of the commissioners under whose charge the exhibits were prepared, or else of the government of the state or country which they represent. Very often the commissioners have been so hampered by the fancies of the mine owners or others in their districts that, though entirely capable of doing so, they have been unable to make a creditable exhibit of the regions they represent. Many of the state exhibits contain a large amount of good and characteristic material which is often rendered useless and often ridiculous by bad and ignorant arrangement; while many otherwise good and characteristic exhibits are rendered very unattractive by the slovenly way in which they are exhibited and the untidiness of the cases and specimens. Of course the last mentioned defects are minor ones, especially to those interested in the subject; but at the same time the neatness of presentation has a great influence on the attractiveness, and hence on the benefits, of an exhibit to the general public. An exhibit which has no natural beauty may be made very attractive by neat and systematic arrangement, while on the other hand, an exhibit of beautiful things may be made actually repulsive by a slovenly and dirty mode of presentation.

The different state exhibits have been collected and displayed by means of the appropriations made by the various state legislatures for such work. As the amount and conditions of the appropriation varied very much in different states, the size and costliness of the exhibits vary accordingly, and often give a very great advantage to the state with the larger appropriation. In criticising an exhibit, therefore, these circumstances must be borne in mind.

Among the best American exhibits are, beginning with the Eastern states, those of Massachusetts, New York, Pennsylvania, North Carolina, Michigan, Minnesota, Missouri, Colorado, Montana, Arizona, Idaho and California; and in Canada those of the Provinces of Quebec and Ontario. Among the other foreign exhibits that of New South Wales is preëminent in the quality, nature and mode of arrangement of the exhibit. The exhibits of Great Britain, Germany, Norway, Sweden, Denmark, Spain, Greece, Austria, Switzerland, Belgium, Italy, South Africa, Ceylon, Japan, and other foreign countries, are good as far as they go.

Many of the mining exhibits of both states and foreign countries are divided, and put partly in the Mines and Mining Building and partly in the individual buildings of the states or countries in question. Such a course is a great mistake, as it renders the exhibit in both buildings imperfect, and those who see the exhibit in one building without knowing that it is supplemented in another, receive an incomplete, and therefore an erroneous, idea of the products of the country represented. Each mining exhibit should be kept together, whether it be in the Mines and Mining Building or in another building.

The exhibits of the New England states are naturally representative of less economic value than those of some of the other states, because, with the exception of building and ornamental stones, most of their mining products are of subordinate importance; but at the same time they display what they have in a systematic and consistent manner. The Massachusetts exhibit is thoroughly characteristic and well arranged, showing not only the economic products, but also many rocks and minerals of purely scientific interest. The Maine exhibit is also characteristic of the state, while the New Hampshire and Vermont exhibits are small but appropriate, consisting largely of building stones, with mica and other minerals from New Hampshire. The granite of New Hampshire and the granite and white marble of Vermont are displayed on a small but sufficient scale.

Coming westward, the New York exhibit is the first one we

find which is representative of great economic importance. It displays its clays, sands, iron ores, building stones, petroleum, salt, etc., in a thoroughly systematic and creditable manner, and gives a very good idea of the relative importance of the different products.

The Pennsylvania exhibit is somewhat more elaborate than that of New York, as it should be, on account of the greater value of its products. Its immense coal and oil resources, together with its iron, clays, glass-making materials, slates, building stones, etc., are very well displayed. A model showing the method of coal mining and relief maps of the anthracite basins and of the whole state add to the attractions of the exhibit. A large series of samples of crude and refined petroleum are an appropriate and interesting feature of the exhibit. A large column of anthracite in a conspicuous position in the centre of the building, and apart from the rest of the Pennsylvania exhibit, represents a vertical section of the "mammoth seam" on the property of the Lehigh Valley Coal Company. A second column, near the main Pennsylvania exhibit, is composed of blocks of the different products of that state, varying in size according to their importance, the smaller blocks being placed successively higher in the column.

New Jersey makes a much less elaborate exhibit than either New York or Pennsylvania, though it is neatly arranged and in some respects it is good. The magnetic iron ores of the northern part of the state, and the clays, marls, and other products are well exhibited. The zinc deposits of Sussex county, however, are only poorly represented, and in this respect the exhibit might have been improved. A glass-plate model of the zinc mines at Mine Hill, Franklin Furnace, Sussex county, is an attractive feature.

Virginia makes a very characteristic and well arranged exhibit, though the fact that the materials exhibited are not in cases detracts from their neatness. A large display of coal and coke, so rapidly becoming the most important products of the state, is made; while the characteristic brown hematite (limon-

ite), the manganese ores, zinc ores, clays, fire-brick, and slate of that state are represented. The Bertha Zinc and Mineral Company displays the zinc ores of the southwestern part of the state and the spelter made from them, as well as statues, wire, etc., made from the spelter.

West Virginia makes a fine display of coal and coke, at present two of its most important industries. Such an exhibit is very appropriate when we consider that forty-eight out of the fifty-two counties of the state are said to contain more or less coal. The salt, mineral waters, crude and refined oils, iron ores, and building stones are also displayed.

North Carolina makes a very neat and characteristic exhibit of iron ores, auriferous quartz, mica, kaolin, asbestos, building stones, gems, etc. The gems include diamond, sapphire, topaz, ruby, beryl, garnet, rutile, chalcedony, etc. A number of interesting models of gold nuggets are also displayed. A number of photographs of different districts form a part of the exhibit, which is neatly and systematically arranged.

South Carolina makes a good exhibit of its great phosphate industry, displaying the crude phosphate and also the manufactured superphosphate. The phosphate industry far eclipses in importance all other mining industries in that state, and the others, such as gold, iron, and manganese mining, in the western part of the state, are of very little and very unstable importance, and are not represented.

Florida, long unknown to the mining industry, has suddenly become of great importance on account of the recent discovery of its phosphate deposits. A small exhibit of these phosphates is made in the Mines and Mining Building, but it is not sufficiently extensive to do credit to a young and rapidly growing industry.

Louisiana makes a very appropriate exhibit of its mining products, among which are lignite, oils, salt, sulphur, marls, clays, chalk, building stones, grindstones, mineral waters, and other minor materials.

The Tennessee exhibit consists mostly of a "Mineral Exhibit

of Harriman, Tenn.," and shows the coal, coke, fossil and magnetic iron ores and brown sandstone produced in that district, together with the pig iron manufactured. The exhibit is creditable to Harriman, but it is a pity that the state of Tennessee in general did not make a full display of its coal, iron, marble, and many other mining resources. The Cleveland Fire Brick Company of Cleveland, Tenn., makes an exhibit of its clays and bricks.

Kentucky makes a good and extensive exhibit of coal and coke, with smaller collections of iron ores, building stones, clays, bricks, etc. A relief map of the state is also an attractive feature of the exhibit. The exhibit contains a large amount of good material, but it might be displayed to better advantage.

Ohio makes a good exhibit of coal, its most important mining industry, and also displays on a smaller scale its crude and refined oil, its salt, clays, iron ores, whetstones, etc. It presents a good model of a salt refining works, and makes a very attractive display of the bricks, tiles, etc., made from its clays.

Indiana makes a good business-like exhibit of just what it has and no more, including a display of coal, clays, building stones, oil, mineral waters, and tiles, and glass manufactured from native products. The exhibit is well arranged and shows all that is necessary.

Illinois makes an extensive display of its clays and the various manufactured articles made from them. A much more extensive mining, mineralogical, and geological exhibit of the state is made in the large state building elsewhere on the World's Fair grounds. This exhibit is well arranged, and truly indicative of the products of the state.

Michigan makes one of the most elaborate exhibits of all the states. The three great mining products of this state are iron, copper, and salt. The first two are excellently represented; the last is much neglected. The different kinds of iron ore are illustrated with numerous specimens; and a large colored cross-section of the Cleveland Cliffs Iron Company's mine is given. A wooden model of the No. 4 Ore Dock at Marquette,

on the Duluth, South Shore and Atlantic Railroad, gives a good idea of the method employed in handling large quantities of ore. The different modes of occurrence of the copper of Michigan are shown by a number of well selected specimens; while the copper in ingots, sheets and wire is well displayed. Interesting wooden models are given of the shaft house and mills of the Calumet and Hecla mine, and of the rock and shaft house of the Tamarack mine. Other interesting features of the exhibit are a number of pre-historic copper implements from Michigan, and arches and columns of brown sandstone produced in the state.

The Wisconsin exhibit contains some good material, but it seems to be arranged more to give prominence to fine specimens than to show systematically the products of the state. The lead and zinc industries of the southwestern part of the state are well represented, but the great iron interests of the northern part of the state are neglected, one pile of ore indefinitely marked "iron ore" and a few other odd specimens being all that are displayed. Some good specimens of granite and columns of red sandstone are also exhibited. In addition, various mineral specimens are displayed, some of which have come from other localities than Wisconsin, and are therefore misleading to the uninitiated.

Minnesota confines its exhibit almost entirely to its greatest mining industry, *i. e.*, the iron of the northern part of the state, and in this department the exhibit is very good. Some building stones and a few mineral specimens are also displayed. A wooden model of the Chandler mine, and a number of maps showing the mines and the geology of the state also form a part of the exhibit.

Iowa makes a small but fairly characteristic exhibit, consisting mostly of coal, building stones, etc. A feature of the exhibit is an artificial "drift" in a coal mine, showing the mode of working and transporting coal on underground tramways. A model of a coal shaft and breaker is also given.

The Missouri exhibit is excellently arranged, and is thoroughly indicative of the resources of the state. The lead, zinc and iron industries are well represented, and pig lead and

zinc spelter are displayed with the ores from which they are derived. A model of the dressing works of the Saint Joseph Lead Company and a relief map of Iron Mountain, colored to show its geology, are interesting features of the exhibit. The coal industry of the state is also represented, together with a number of building stones, ochres, etc., and a fine collection of calcite and other mineral specimens from the lead and zinc mines.

The South Dakota exhibit consists largely of tin ore, auriferous quartz, mica and some argentiferous galena, and is essentially a Black Hills exhibit. "Lode" tin ore and stream tin, as well as pig tin manufactured from the ores, are exhibited in large quantities. A large column of tin ore, from the property of the Harney Peak Consolidated Tin Company, contains a placard stating that the capital invested is $3,500,000, a fact it is difficult to understand they should wish to make so prominent in view of the unproductive history of their operations. The auriferous quartz is a good exhibit and characteristic of the quartz deposits of the Black Hills. Some beautiful pieces of Arizona silicified wood, which were polished in Dakota, are exhibited, but in lack of the proper explanation as to their source, they are misleading, as they suggest Dakota as the region from which they were derived.

Kansas makes a very good exhibit of lead and zinc ores with the pig lead and zinc spelter derived from them. The exhibit also includes a display of rock salt, gypsum, building stones and other minor products. The exhibit is small, but it is characteristic of the state and is well arranged.

Montana makes a good exhibit as far as it goes, but many localities and many important deposits are not represented. The best exhibits are from the great mining camp of the state, *i. e.*, Butte City. The great copper and silver interests of this district—especially the former—are well presented, and large quantities of sulphide copper ores, and the metallic copper made from them, are displayed. A quantity of gold quartz, and an interesting collection of gold nuggets are also a part of this exhibit.

The most prominent feature of the exhibit, however, is a solid silver, life-size statue of the celebrated actress, Ada Rehan, standing on a globe which in turn rests on a base of solid gold. The whole work represents several hundred thousand dollars worth of precious metals, all the products of Montana mines.

Wyoming makes a neat and effective exhibit. It consists largely of coal in columns and blocks, jars of petroleum, blocks of sulphate of soda and sulphate of magnesia, "lode" tin ore and stream tin ore from the northeastern part of the state, adjoining the Dakota tin region, iron ore, copper ore, auriferous quartz, lead carbonate, asbestos, agates, clay, sulphur, building stones, etc.

Colorado makes a fairly good display of its silver-lead ores, copper ores, gold ores, coal and manufactured lead and copper. Some of the building stones and iron ores of the state are shown, but these materials are not fully represented. An instructive feature of the exhibit is a series of cases of gold nuggets, dust gold and sheet gold from Breckenridge, Colorado. Many of the important mining camps in the state are represented, especially Aspen, Leadville, Creede, Cripple Creek, etc. The exhibit is fairly good, but a state of such immense mining wealth as Colorado could have made a much better one.

The Utah exhibit contains a large amount of valuable material, but it is too much crowded and badly arranged. The desire for a display of brilliantly contrasted colors has in some cases entirely upset the systematic arrangement of the exhibit, and has given part of it the appearance of the toy boxes with pieces of minerals glued on the outside that are sold to confiding tourists in our western states as works of art and value. The exhibit represents the varied mining industries of the territory, among the most important substances being coal, gilsonite, albertite, elaterite, asphalt, oil shales, sulphur, salt, iron ores, copper ores, silver and gold ores, building stones, etc. The exhibit of articles "japanned" by the gilsonite varnish are of interest. Some large specimens of silver-lead ores and ores containing chloride of silver are characteristic of the mines producing them.

The New Mexico exhibit contains some good material, but is not very well exhibited. The silver ores, one of the most important products of the territory, are well represented, being grouped according to the localities from which they came. A small cabin in the centre of the exhibit is composed of silver, lead and gold ores from different localities. A stuffed burro carrying a prospector's camping outfit is a somewhat sensational feature of the exhibit. A column of coal from Blossburg and Los Cerillos represents the growing coal industry of the territory.

The Arizona exhibit is very good and well arranged. It is truly indicative of the products of the territory. The most important features of it are the copper ores, the silicified wood and the gold ores. The copper ores especially are well represented, and a beautiful column of green and blue carbonates of copper from Bisbee forms the most prominent feature of the exhibit. While in the Michigan exhibit we see only native copper, in the Montana exhibit only sulphides of copper, here in the Arizona exhibit we see mostly carbonates of copper with some silicate and oxide of copper. Thus in these three copper districts we have representatives of three great classes of copper ores. An interesting feature of the Arizona copper exhibit is a series of models showing the underground workings of the Copper Queen Consolidated Mining Company at Bisbee. The Old Dominion Copper Company whose mines are at Globe, Arizona, makes a very excellent exhibit of its ores and its copper ingots in a cabinet alongside the main Arizona exhibit. The gold ores of Arizona are well represented, and some of the silver ores are also shown, while the beautiful polished sections of the celebrated silicified wood of Arizona form an attractive and interesting feature of the exhibit. Some of the so-called "onyx" is also exhibited in polished slabs.

Nevada makes a fairly good exhibit of its mining products, mostly the silver ores abundant in this region, and the accompanying minerals. A "special exhibit" from Eureka, Nevada, contains a number of interesting specimens.

The Idaho exhibit is fairly good, but not thoroughly characteristic of the state. The most prominent features are the silver-lead ores from the northern part of the state, green copper carbonates, and a mineral water known as "Idanha" from Soda Springs. A number of photographs of different mining districts are of interest.

Washington makes a fairly good, but poorly arranged, exhibit of gold ores, silver ores and silver-lead ores, and a few other products. The coal resources of the state are entirely neglected, though they are well represented in the Washington state building. This separation of the mining products of a region, and their distribution partly in one building partly in another, is a great mistake, as it gives a person who sees only one of the exhibits an incomplete and therefore an erroneous idea of the resources of the state. The exhibit should be all in one or the other building.

Oregon makes a large exhibit of auriferous quartz and shows a very good working model of hydraulic mining. Some building stones are also represented. The exhibit is very good so far as it goes, but it does not do justice to the state, as many of its developed and undeveloped resources such as iron, coal, etc., are not represented.

California makes a good exhibit, and one characteristic of the resources of the state. It is very appropriately composed largely of gold ores and a display of the methods of gold mining. The auriferous quartz of the celebrated Grass Valley and other localities is well represented. An interesting feature is a wooden model by A. C. Hamilton showing a system of mine timbering. Stibnite from San Benito county and the metallic antimony derived from it are also represented. Among the other prominent features of the exhibit are iron ores, asphalt, oils, slate and a beautiful display of ornamental and building stones. The so-called "onyx" from San Luis Obispo county, and the colored marbles from Inyo County are exceedingly beautiful. The exhibit is entered through arches built of the various ornamental stones of the state, while blocks of rock containing the beauti-

ful rubidolite, or pink tourmaline, are displayed at the entrance. Elsewhere in the building is a fine and beautiful exhibition of the so-called "onyx" from New Pedrara, in Southern California.

Besides the California exhibit in the Mines and Mining Building, an interesting collection of the mining products of the state, especially gold ores and native gold, are contained in the California state building. Somewhat similar specimens, however, are in the Mines and Mining Building, so that the division of the collection in this case is not especially injurious.

Among the foreign collections, that of New South Wales stands preëminent. The great mining wealth of this province is exhibited in a very systematic and thorough manner, and an excellent idea is given of the resources of the region. There is no attempt at a display of a sensational character as is seen in some of the exhibits, but everything is shown in a plain business way, in large quantities and in properly selected samples. Among the most prominent features of the exhibit are its tin, gold, silver, lead, antimony, copper, iron, manganese, and chromium ores, its coal, graphite, building stones, etc. The ores exhibited are average samples such as are sold in the market, and therefore give a true idea of the deposits represented. In many cases, as in antimony, tin, etc., the metals are exhibited in blocks or pigs, with the ore from which they are derived. The ores of the great Broken Hill silver mine and the statistics of its production are of interest to those acquainted with this famous mine. The exhibit of the tin industry is of great interest as representing the development of this comparatively new tin region, which has only been much developed since 1872; while the coal exhibit shows not only the bituminous coal of the region, but also the kerosene shales, etc.

Among some of the other foreign exhibits those of the provinces of Ontario and Quebec are very good, showing as they do the various products of those provinces in a thorough and systematic order. The other provinces of Canada do not make such good exhibits. A collection of the rocks of Canada by the Geological Survey is of great interest. Mexico exhibits a great

amount of material, but it is so arranged that it loses much of the benefit that it might afford to the exhibitors and to the public. Brazil makes a fairly good exhibit, while Chile, Ecuador and other South American countries are also represented. The South Africa diamond exhibit is very interesting as showing the mode of occurrence, methods of mining and washing, and cutting the diamonds. The exhibits of Great Britain, Germany, Japan and other foreign countries are also of interest. La Societé "Le Nickel" of France makes a very interesting exhibit of its nickel ore in New Caledonia, the nickel derived from it, pictures of the mine and various other interesting features of the industry.

Many others of the numerous exhibits of American and foreign products in the Mines and Mining Building might be mentioned, but lack of space forbids further elaboration. The same cause makes it necessary to discuss in another article the extensive and excellent exhibition of the United States Survey in the Government Building.

R. A. F. PENROSE, JR.

THE LAS ANIMAS GLACIER.

One of the largest of the extinct glaciers of the Rocky Mountains was that which occupied the valley of the Las Animas river. This stream originates in the San Juan mountains in southwestern Colorado, and flows nearly south to its junction with the San Juan river in New Mexico. The San Juan mountains, with their outlying spur, the La Platas, are the first high mountains encountered by the moist winds from the direction of the Gulf of California on their way northeastward; and although so far south, this region has perhaps the heaviest snow fall in Colorado, as Frèmont found to his cost. His expedition up the Rio Grande attempted to penetrate the snowiest part of the mountains.

Silverton is situated about fifteen miles from the head of the valley, and Durango about sixty. About one mile north of Durango, near Animas City, two well defined morainal ridges extend across the valley of the Las Animas, and from thence a plain or series of terraces of water-washed morainal matter extends for several miles down the river. I have not explored far below Durango, and do not know the extreme limit of the ice. At Durango the ice rose to about the same height as the mesa lying east of the city, on which is the reservoir of the water-works, 300 or more feet above the valley terrace. This is proved by the fact that a thin sheet of morainal matter covers the slopes of the bluff and extends back for a short distance on top of the mesa (up to 100 feet); whereas, beyond that the top of the mesa is a base level of erosion in the sedimentary rock, with none of the far-traveled bowlders that abound in the moraine stuff. The glaciated bowlders are largely composed of rocks found only near the head of the valley, such as volcanic rocks, Archean schists and granites, Paleozoic quartzites, etc. Most of these must have traveled thirty to sixty miles.

About a mile above Durango, at the most distinct of the terminal moraines thus far noted, the valley widens to about one mile, and continues pretty broad for twelve miles or more northward. The valley is here covered with rather fine sediment. It is marked on Hayden's maps as alluvium, but the glacial character of the terraces near Durango is not recognized, though deposits substantially the same, situated a few miles northwest of Durango in the La Plata valley, are markedly morainal.

The post-glacial history of the valley was as follows. The terminal moraines near Durango formed a dam that held in a lake. This lake was partially filled with sediments, and at the same time the river was cutting down through the morainal barrier. The outlet is now so low as to drain the lake, except there are some low, marshy flats where the water stands only a short distance below the surface of the ground.

I have visited many of the tributary valleys of this river above Silverton. Every cirque had its glacier that flowed down into the larger valleys. The volcanic rocks of that region weather readily, so that one seldom finds glacial scratches except at recent excavations for roads and mines. It has therefore been a matter of considerable difficulty to determine the depth of the glacier of the main valley. By degrees the estimated depth increased until a few months ago, when I found scratches well preserved on quartzite at a height estimated at 1,500 feet above the Las Animas river. This was near the Mabel mine, about four miles southeast from Silverton, and not more than 500 to 800 feet below the top of the ridge which here borders the valley on the east. The glaciated rock is situated on a long gentle westward slope, while the scratches have a north and south direction. Local glaciers would have flowed westward. These scratches are therefore parallel with the movement in the main Las Animas valley, under conditions where no local glacier could have produced them.

It thus appears that near Silverton (elevation of valley about 9000 feet) the Las Animas glacier was 1,500 or more feet deep, while at Durango (elevation about 6000 feet) it had a thickness

of about 350 feet and a breadth of one-fourth mile or more. Its extreme length was more than sixty miles, probably about seventy miles. The average slope of the upper surface was eighty-three feet or more per mile. For fifteen miles its breadth was one or more miles.

From the terminal moraines near Durango, the valley of the Las Animas is for several miles southward covered by a plain of water-washed material, from coarse gravel up to bowlders three to five feet in diameter. Some of these have glacial scratches, though most have been so much rolled and polished as to preserve no distinct scratches. The lower terraces at Durango are of this character. They are typical of the overwash gravels found in many of the Rocky mountain valleys. The subglacial streams poured out their load of sediments in the valley in front of the ice, where they were mixed with some material dropped directly from the ice, and hence not rolled far enough to obliterate the glacial scratches. More or less of this glacial gravel is found in all the wider parts of this valley and its tributaries above Silverton until we reach within five or ten miles from the heads of the valleys. During the retreat of the tributary glaciers they poured out much less glacial gravel after they came to be ten miles or less in length, and what there was is usually but little water-worn.

Since the above was written further exploration reveals the fact that a large glacier originated on the eastern slopes of the La Plata mountains, and flowed southeastward down the valley of Junction creek and joined the Animas glacier in the northern part of Durango. Five hundred or more feet above the creek it left a lateral moraine on the top of the narrow ridge which borders the valley on the south. The moraine consists chiefly of the eruptives and metamorphosed sediments found in the La Platas, and but little of the local rocks.

The drift terraces near Durango are found at different levels. The lowest terrace is that above described, and consists of glacial gravel mixed with matter that has been but little rolled. The higher terraces have the appearance of ordinary valley terraces as seen from the river, but in some cases do not extend

back to the sides of the valley. The largest of these lies on the east side of the Animas river, between Animas City and Durango. It is more than a mile in length, and the outer or distal side ends in a bluff twenty to forty feet high. At its north and south ends this curved terrace approaches near to the mesa bordering the valley, thus enclosing a depression several hundred yards wide that is occupied by a small lake in time of violent rains. A basin of this kind could not have been hollowed out by the river, and, besides, the terminal moraines of Animas City extend across the north end of the basin. It is evident that this terrace was formed laterally to the glacier in substantially its present form. It contains great numbers of boulders up to fifteen feet in diameter, but a large portion of it has been very much water-rolled. The most probable interpretation is that these higher terraces began to be deposited at the outer edge as a lateral moraine. Then as the ice gradually receded morainal matter and glacial gravel were simultaneously deposited in the space between the moraine and the retreating ice. This hypothesis well accounts for the fact that morainal and water-rounded matter are so intimately mixed in the terrace, also that the overwash did not spread laterally back to the margin of the valley. We thus have the terraces ending distally in the steep slope characteristic of the moraine rather than the more gentle slope of the overwash apron. Most of these higher terraces end proximally (next the river) in rather steep slopes or bluffs rising twenty to seventy-five feet above the lower terraces. No city of Colorado has so much of glacial interest within its limits as Durango, unless it be Leadville.

It is an interesting fact that the cols of the mountain ridges of this region are glaciated almost or quite to their tops. Thus at Stoney Pass, the first pass north of Cunningham Pass, I saw well-glaciated rocks within 200 feet (horizontally) from the top of the pass. From the top of this pass the mountain slopes steeply northwestward toward the Las Animas valley, and in the opposite direction down the Rio Grande valley. The rocks at the summit were weathered, and it was not evident whether

the top of the ridge had been glaciated, but it is certain the ice or snow flowed in opposite directions from the col. On each side of the pass, peaks of the Continental Divide rise above the col to a height of 1000 to 2000 feet. It is evident that the snow from these peaks would flow or slide from each side down into the pass, and maintain a supply of névé or ice right on top of the ridge in the pass. The pass is about 11,800 feet high. It thus appears that the snow fields reached nearly to the tops of the mountains, say about 12,000 feet in the cirques and passes, while above this the discharge was probably in large part by avalanches.

Durango city is situated in about N. Lat. 37° 16′, a few miles north of the end of this glacier. It is to be carefully noted, in the study of the climates of the glacial epoch, that a glacier nearly seventy miles long reached so far south. Apparently the most snowy part of Colorado now was also the most snowy then.

During the retreat of this glacier it left numerous small retreatal moraines, both in the main valley and in the tributary valleys above Silverton. One of the most accessible is near the junction of the two branches of Mineral creek, about three miles northwest from Silverton.

It is noticeable that the proportion of moraine stuff left by this glacier is small as compared to the glacial sediments. Nowhere have I yet found very noticeable ridge or terrace lateral moraines. This is in part due to the steepness of the hills that border the sides of the Animas valley. There is usually a scattering of glaciated matter on these hill slopes, and where they are less steep, or in lee of ridges projecting out into the valley, local morainal sheets are sometimes found that have a depth of twenty feet or more. Small terrace-like lateral moraines extend for a mile or two north of the terminal moraines of Animas City near Durango. Probably the snow avalanches and flowing névé carried down débris and incorporated it with the glacier proper, so that there were no large surface lateral moraines as in some of the valleys of the Alps, or in the Arkansas and some other valleys of Colorado. In other words, the débris of this glacier was largely englacial and basal.

George H. Stone.

STUDIES FOR STUDENTS.

CONDITIONS OF SEDIMENTARY DEPOSITION.

EROSION.

Erosion consists of fragmental reduction and abrasion of rock masses, chemical disintegration of rocks and transportation. The three sub-processes may be called rock-breaking, rock-decay and transportation. They are conditioned by declivity, lithologic character and climate.

ROCK-BREAKING.

Favorable conditions:

(*a*) Steep slopes.
(*b*) Bare rocks.
(*c*) Cleaved and jointed rocks.
(*d*) Alternation of hard and soft beds.
(*e*) Rapid changes of temperature.
(*f*) Aridity and high winds.
(*g*) Abundant rainfall, in the absence of vegetation.
(*h*) Sea cliffs.

Products: Shingle, gravel and sand of mixed mineralogical composition.

ROCK-DECAY.

Favorable conditions:

(*a*) Gentle slopes.
(*b*) Porous soil.
(*c*) Soluble rock constituents.
(*d*) Carbonic acid and other acids of organic decay.
(*e*) Abundant rainfall in the presence of vegetation.
(*f*) Prolonged transportation of gravel and sand.

Products: Rock cores of disintegrated masses, sand, (chiefly quartz-sand), residual clays, and lime, magnesia, iron, etc., in solution.

TRANSPORTATION.

Favorable conditions:

(*a*) Steep slopes.
(*b*) Abundant rainfall.
(*c*) Absence of vegetation.
(*d*) Floods
(*e*) Fine detritus.

By comparison of the statements of favorable conditions for rock-breaking, rock-decay and transportation it becomes apparent that breaking and decay are favored by opposite conditions in nearly all respects, while breaking and transportation are most efficient under like conditions. But breaking promotes decay, and decay aids transportation, by reducing the size of the particles to be decomposed and carried, and the maximum effect of erosion is probably attained when rock-breaking is active among greater elevations, and rock-decay and transportation are both proceeding energetically on lower slopes.[1]

The amount of material furnished by erosion is an important consideration in reference to the rate of accumulation of sediments over a given area, and is a condition not to be overlooked in comparing thicknesses of deposits with the lapse of geological ages.

SEQUENCE OF SEDIMENTS.

Shingle, gravel, sand, clay and silt are products of erosion of rock masses. They are produced either by mechanical breaking or by chemical disintegration. These two subprocesses of the general process of erosion are favored by unlike conditions. Those conditions which render breaking most efficient are unfavorable to immediate disintegration; and those conditions which promote disintegration limit breaking. Breaking, the reduction of a rock mass to small pieces, is usually

[1] Gilbert, Henry Mts. p. 105.

the antecedent of disintegration, of decay, but the two are not most efficiently active at the same time. Now their products differ. Rock breaking yields shingle, gravel, coarse sand of mixed mineralogical composition, and no chemical solutions. Rock-decay yields directly no shingle or gravel, but produces sand, chiefly quartz-sand, clay, silt and chemical solutions. Hence, if the products of rock-breaking are deposited unchanged in the sea, there will result one class of sediments from which we may infer corresponding conditions of erosion of the parent land; and if the products of rock-decay are deposited we must infer other conditions of erosion.

Declivity is the chief factor which determines either rock-breaking or rock decay. Rock breaking occurs on steep slopes, that is, among hills or mountains; rock-decay takes place chiefly on gentle slopes, that is, in valleys or on plains. Hence the sediments may indicate the topographic phase of the parent-land.

They may indicate topographic phase, not permanent topographic character, for relief of the land surface is transient. The steeps of mountains become the slopes of hills, the hill slopes sink to plains and plains to base-level; and erosion pauses till renewed by uplift. So the conditions of rock-breaking pass into those of rock-decay, and the product of the two processes may appear in sediments, the older gravel and sand beneath the younger sandy clay and clay.

The possible sequence of unlike sediments does not stop with the finer mechanical products of disintegration; chemical solutions may be related to chemical or organic deposits, and these have their place among strata. The amount of lime and magnesia carried annually from a given land area is directly related to the efficiency of rock-decay, and so among other factors to slope. Rock-decay is limited on the one hand by declivities, which promote the rapid running off of rainfall, and on the other hand by the accumulation of a deep covering of soil, which prevents percolation. Other things being equal, it is probably most efficient during the period corresponding with the life of low hills and sloping plains. If at any time chemical solutions from

the land determine the deposition of calcareous formations they will do so most efficiently during this topographic phase, and in the absence of mechanical sediments the corresponding deposits will be limestones or dolomites. As the topographic phase passes to its close and the sloping plains sink to base-level, the power of streams to transport mechanical sediment fails, and rivers finally carry only silt in lessening proportion; hence the upper portions of a great limestone deposit may be less clayey than the lower. Furthermore, the mantle of residual clays, accumulating upon the extended base-level, will check solution, and thus, in so far as the deposition of limestone is influenced by contributions from the land, will limit the growth of the formation; and with the cessation of both mechanical and chemical supply, terrigenous deposits will cease to form beneath the sea. Then, while these conditions endure geologic ages may pass without record in sediments unless there is a marine source of supply.

Thus far this statement has tacitly assumed a constant relation of elevation between coast and ocean. Assume that the long quiet, which has been necessary for the reduction of a mountain range to base-level and the deposition of the corresponding sediments, is interrupted by sinking or heaving of the land area. The surface is low, flat and covered by a mantle of residual sand and clay intimately mingled. Moderate subsidence must lead to extensive transgression and the invading sea, margined by tide flats, will spread arenaceous, clayey deposits, bearing the marks of shallow water formations and resting unconformably upon the ancient rocks. If the residual soil be red, the sediments will be of similar color, since the process of deposition on tide flats does not involve much attrition and the ferruginous coating of the grains will remain.[1] The base of the deposit may be a zone of transition, composed of cores of undecomposed rocks, imbedded in more or less re-arranged products of partial decomposition.[2]

[1] Bull. U. S. G. S. No. 52. I. C. Russell, Subaërial Decay of Rocks and Origin of Red Color of Certain Formations.

[2] R. Pumpelly. The Relation of Secular Rock Disintegration to Certain Transitional Schists. Bull. Geol. Soc. of America. Vol. II., p. 209.

Or, on the other hand, moderate uplift of the base-leveled continent, must cause the revived streams rapidly to sweep into the sea the mass of insoluble clay and sand which formed the residual mantle. Thus the limestone deposits will be succeeded by a thickness of shales of a more or less arenaceous or clayey character.

From these considerations it follows that a complete topographic cycle may be related to a sedimentary sequence composed of a sandy base, a limestone middle and a shale top. Newberry first noted the frequent recurrence of this sequence, and sought an explanation in conditions related simply to the sea; its advance, presence and retreat. When he made his generalization the base-level had not been recognized as a result of continued erosion, nor had Gilbert analyzed the process of erosion; and Davis had not described a topographic cycle. These contributions to the science have widened the field of inference, and the topographic phase of the land can no longer be disregarded in the discussion of the deposits of the sea.

But it should not be forgotten that the inference from sediments should be confined to the topographic phase of a belt of land extending back from the shore to a moderate distance only. The products of rock-breaking disintegrate during prolonged transportation and mountains remote from the coast are not indicated in deltas of great rivers. A student of the deposits of the Mississippi would not infer the height of the Rocky mountains, but the sands of the Klamath river bear witness to the nearness of the coast range.

The analysis and discussion of conditions which govern the character of the material contributed from land to sea might be extended in detail, and illustrated by descriptions of sediments in existing rivers, but the subject is worthy of independent treatment.

SEDIMENTATION.

Sedimentation consists of three sub-processes, sorting, distribution and deposition. These are effected by waves and undertow, tides, winds and oceanic currents and are modified

by the relation of volume of sediment to the force of waves or currents. If the analysis be based on the sub-processes and conditions which favor them, it may be stated and discussed as follows:

SORTING.

The conditions under which sorting is more or less efficiently carried on are three in number.

Favorable conditions:

(*a*) Vigorous wave action accompanied by strong undertow.

(*b*) Prolonged transportation in consequence of deep water and continuous currents.

(*c*) Moderate volume of sediments.

The conditions under which sorting is not accomplished are the reverse of these, namely:

Unfavorable conditions:

(*a*) Feeble or diffused wave action.

(*b*) Concentrated deposition.

(*c*) Excessive volume of sediments.

It will be profitable briefly to discuss these positive and negative conditions.

(*a*) *Vigorous wave-action.*—The force of waves is determined by their fetch and the strength of winds. In the study of modern beaches the latter is important, since it controls the form and the greatest storm[1] fixes the maximum size of detritus moved; but in considering fossil beaches as strata we deal with sands which have been so rearranged during submergence that the beach form is lost. However the former condition, the fetch of the waves is more constant, and the force of the waves determined by it may be inferred from the nature of the beach deposits.

The efficiency of waves of a given force is determined by the concentration of their blows, and this is conditioned by the slope against which they break. If relatively deep water prevails

[1] For full discussion of wave erosion and deposition, see Lake Bonneville, by G. K. Gilbert. Monograph 1, U. S. C. S.

to the shore, whatever force the waves may have is expended at the water's edge. On a bold coast they carve sea-cliffs and grind shingle with sand. Such are the coasts of New England, Oregon, California, and of all the Pacific side of South America. The resulting sediments are composed of worn but fresh rock fragments and thus bear witness to rapid mechanical erosion, like the products of rock breaking on steep declivities. On a shore of incoherent materials waves stir, wash and separate fine and coarse, light and heavy particles. Under favorable conditions of depth of water and long fetch, waves thus sort a heterogeneous mass of gravel or of residual sand and clay more efficiently than any other agent, and leave clean cross-stratified beach sand and gravel with boulders, while the finer materials are swept away. The southeastern shore of Long Island presents a conspicuous example of this, and the westward drift of the beach-sands is illustrated in the fact that shingle beaches prevail toward the eastern end of Montauk point, and the sands there washed from the bluffs of glacial gravel form long barriers along the coast to the westward.

If, on the other hand, waves break in shallow waters at a distance from shore they there build a barrier, and the height to which they build it above high tide is the measure of their maximum power during great storms. Within the barrier then extends a lagoon. The whole Atlantic coast from Long Island to Florida is thus fringed by the features of prevalent wave action, due to the great fetch from off the ocean and the gradual slope of the continental platform.

(*b*) *Prolonged transportation.*—Sorting is also accomplished to some extent, though less perfectly, by deep water and continuous currents. Sediments settle unequally according to size and specific gravity of particles; therefore the largest and heaviest reach bottom first, the finer and lighter later, and the finest and lightest last. If the conditions of supply or current be intermittent over any area then each incident of deposition will be marked by a layer composed of coarsest grains below and finest grains on top. This is the nature of deposition in tidal estua-

ries. If, on the other hand, currents be continuous and constant, the zones of sand, clay and silt deposits will occur each beyond the former. But this is a question of distribution as well as of sorting of sediments.

(*c*) *Moderate volumes of sediments.*—Sediments are also more or less completely sorted by waves or currents according to the relation between the volume of sediment and the force of the sorters. When waves breaking upon a coast have only the product of wave erosion to handle they sort most completely; the material is washed again and again until no trace of clay remains mingled with the sand grains; and the under-tow, burdened only with the clay washed out by the waves and the fine products of abrasion, carries them all away. But where a river pours out a large volume of sediment, and waves or currents are consequently overloaded, both sorting and transportation fail to a greater or less degree. Deposition takes place too rapidly for the separation of fine from coarse and the deposit is of mixed character. The effect of waves is then seen in ripple-marked and ill-assorted beds of tide flats.

DISTRIBUTION.

The conditions under which sediments are more or less widely distributed, depend upon movement of the waters and the nature of the sediment; those favorable to distribution are:

Favorable conditions :

(*a*) Efficient wave action prevailing from one direction oblique to the shore.
(*b*) Continuous currents.
(*c*) Uniform or gradually increasing depths of water.
(*d*) Fine or light sediment.

The reverse of these conditions favor deposition, and will be discussed in that connection.

(*a*) *Efficient, oblique wave action.*—Distribution of shore drift is fully discussed by Gilbert, and has already been referred to in stating the effect of sorting by waves of the Atlantic on

the south shore of Long Island, and the formation of barriers of wave-washed sand.

(*b*) *Continuous currents.*—Distribution by continuous currents is the condition usually assumed as having controlled the arrangement of sediments in seas of past geologic periods. In consequence of the sorting which results from different rates of settling clay is carried beyond sand, and silt is distributed more widely than clay. The prevailing current, which thus distributes, is under-tow more or less checked and assisted by tides. If the submarine slope descends from the shore steeply into oceanic depths, the force of undertow must rapidly be dissipated, but pebbles and sand move easily down the steep incline, and form a sequence of continually smaller particles, which is usually not very extended. This is the case on the western coast of South America. If, on the other hand, the seaward slope is very gentle, undertow loses force more gradually and fine sands may occur to great distances from the shore, with clay and silt deposited beyond them. This is the case off the Atlantic coast of the United States where tides probably form a powerful alternating influence; there the continental plateau is covered with sand to its outer rim, as is shown by soundings by the Coast Survey. But the force of undertow is determined in the first place by the force of waves, and it can be effective in distributing only where waves are powerful. It fails in limited seas except in a very narrow zone along shore.

Ocean currents also distribute sediments very widely. The terrigenous deposits of the Bay of Bengal and Arabian sea, mapped by Murray,[1] covering 1,600,000 square miles, owe their wide spread distribution apparently to the ocean currents which circulate east and west alternately with the changes of season in these great bays.

(*c*) *Uniform depths.*—Changes in depth of water affect the velocity of a current and thus modify its power to distribute sediment. Narrowing channel or shallowing water may cause a

[1] Scottish Geogr. Mag., Vol. V. No. 8, Aug. 1889.

current to scour and take on more load; but broadening channel or deepening water tends to cause it to deposit. The Gulf stream scours the straits of Florida and the Blake plateau, but deposits a silt bank on the lee side of the latter.[1] Only in the broad expanse of deep water does it widely distribute sediment.

(*d*) *Size of particles.*—Fine or light sediment is most widely distributed. The "blue muds" which form the terrigenous deposits beyond the littoral zone consist of particles of an average diameter of .05 mm.

Deposition occurs whenever a body of water becomes overloaded with substances in suspension or in solution. According to the condition which determines the result the deposits may be classified as mechanical, chemical and organic.

MECHANICAL DEPOSITION.

Favorable Conditions:

(*a*) Arrest and retreat of waves; beaches and sand deposits from undertow.

(*b*) Current entering still water and slowing; lake-deposits.

(*c*) Alternating currents in fresh and salt water; estuarine deposits.

(*d*) Rise of salt water surface at a river's mouth in consequence of winds, long continued from one direction; delta of the Mississippi.

(*e*) Flotation of fresh water on salt; bars of the Mississippi.

(*f*) Floculation of sediments in salt water.

(*g*) Expansion and diffusion of a current in rapidly deepening water; silt deposits on the edge of continental plateaus.

(*h*) Final subsidence from oceanic circulation.

Arrest of Waves.—(*a*) Beaches are formed where waves break. The rotary oscillation which constitutes waves in deep water becomes a motion of translation when the water shallows sufficiently and the mass of the broken wave, rushing forward,

[1] Agassiz. Three Cruises of the Blake. Bull. Mus. of Comp. Zoölogy. Harvard College. Vol. XIV.

carries up material stirred from the bottom. The finer particles are swept back by the undertow, the coarse are placed by the greater waves beyond the reach of the lesser. Thus waves, constantly in advancing, take material from the lower part of the slope to carry it up, and in retreating sweep back more or less of their load with them. If the slope be gentle they thus take from the lower to add to the upper part, and therefore they increase the declivity until the seaward profile becomes so steep that the load carried in retreat balances that advanced. This is the profile of equilibrium, which waves perpendicular to the trend of the beach do not change, unless they are of unusual force. Waves oblique to the beach-slope, scour, transport and deposit the same sands repeatedly, and if the oblique advance be prevailingly from one direction the effect is to move the beach longitudinally. Then the beach, in any one section, continues, while the supply of sand is continuous; but when the supply ceases the beach is gradually moved onward in the direction of the prevailing wave action, and the material beneath the beach sands is exposed to wave erosion.

A beach itself is but a narrow zone; it cannot constitute a wide-spread formation any more than a line can constitute a plane. But if a line be moved in one direction parallel to itself it will develop the plane, and in the same manner if a beach advances landward it may spread a formation. This advance may be a result of wave erosion, which carving a sea cliff on a bold shore planes a surface of marine denudation. The beach deposit is then a basal conglomerate. Or, the land reduced to a low surface by subaërial erosion may subside slightly in reference to sea level, and the sea, transgressing, will rearrange the superficial formations. If the waves have power to handle the material the sea is margined by beach sands. If they cannot efficiently sort it the land will merge in tide-flats with the water.

A beach is not only narrow, it is also shallow; waves build on the surface over which they break, and the height to which they may build does not exceed a few feet. Therefore, beach deposits cannot form thick strata.

The undertow rolls coarser sand and pebbles down the slope of the bottom, and carries out in suspension silt and clay with more or less fine sand. The rolling of coarser sands is promoted by a steep slope. The transportation of finer sands depends on the endurance of the undertow of a given initial strength; and this endurance will be the greater the more gradual the seaward slope and the stronger the tides. The amount of sand thus deposited is limited only by the supply, and sandy strata may, therefore, attain great thickness and have great extent seaward from a fixed beach line. If the coast be continually maintained by uplift or renewed by volcanic flows the work of the waves may be of like duration and the record will be correspondingly voluminous. Professor Chamberlin mentions the great conglomerates of Lake Superior in this connection.

Beach deposits, strictly speaking, are usually of quite coarse sand, clean and characterized by marked and irregular cross-stratification. Sand deposits from undertow graduate from clean to muddy sands, becoming ever finer seaward, and are horizontally bedded or massive.

Therefore the interpretation which may be put on strata, deposited by the arrest and retreat of waves, are:

(1) A basal conglomerate is significant of an horizon of wave erosion, due to transgression of the sea and probable subsidence of the land. If the basal contact be clean and sharp the waves probably carved a shore cliff in hard rocks. If, between the parent rock and the later sedimentary formation, there be a zone of transition composed of boulders, sand and clay of mixed mineral composition, the waves probably rearranged the cores and finer products of a surface of partial subaërial rock decay. A basal conglomerate of any variety is a definite proof of an unconformity by erosion; it is often the only fact by which such an unconformity can be distinguished from an overthrust fault.

(2) A deposit of clean sands is proof of the former existence, somewhere, of a beach on which they were washed; but the place of deposit may have been remote from the line of the beach. Coarseness of grain suggests proximity of land and vice

versa, but such suggestions need to be qualified by considering the probable fetch of the waves, the corresponding initial strength of the undertow and the declivity of the seaward slope.

A thin stratum of coarse cross stratified sands may represent a transgression by a beach-building sea over a subsiding land. A thicker stratum may have been formed by deposits from undertow behind a stationary or advancing beach line, and if such a deposit shows cross-stratification throughout, it was washed by conflicting currents, probably tidal, during its accumulation.

The deposition of beach-washed sands is consistent with constant or subsiding level of the land in relation to the sea. It does not appear that it is likely to occur during uplift from the sea except in the comparatively rare case of the rapid elevation of a bold coast range with preponderance of rock-breaking over rock-decay.

The occurrence of a stratum of sandstone is not evidence that during its formation the land furnished no other detritus. If the sands be of mixed mineralogical composition, bold declivities on land and prevalence of rock-breaking are indicated; but if the sands be chiefly quartzose it is more probable that the waves have sorted the waste of a residual mantle.

Quiet Water.—(*b*) When a current enters a body of quiet fresh water, unvexed by tides or winds, as a stream enters a lake, the inertia of the greater mass and the diffusion of the stream in the greater volume checks the current, and it drops whatever sediment it may have carried. The laws of this simple case can be formulated mathematically, and Babbage has calculated the distance to which sediments of an assumed character would be transported by a river current of assumed velocity entering a salt-water body, whose bottom has an assumed slope; he neglects the difference of density between fresh and salt water, and assumes an off-shore current equal to that of the river at its mouth.[1] The conclusion is determined in advance, and cannot be applied to the interpretation even of lake sediments, since the assumed conditions of sediment and current are hypo-

[1] Hand Book of Physical Geology, 1884. A. J. Jukes-Browne, p. 185.

thetical. An existing case, which approaches the conditions assumed by Babbage, is that of the Rio Uruguay, which is described by Revy.[1]

"The little town of Higueritas, also called Nueva Palmira, is situated in latitude 33° 52′ S., long. 58° 23′ W., in the Banda Oriental, at the junction of the Uruguay with various branches of the Parana, all of which discharge jointly their volume into the La Plata. Three miles below Higueritas, at Punta Gorda, the La Plata proper commences; three miles above Higueritas the Uruguay opens into a lake from 4 to 6 miles wide and about 56 miles long. There are no islands on this lake, although, with the exception of a deep channel half a mile wide of steep sides and submerged, the lake is shallow; it may be called the estuary of the Uruguay. A little above Fray Bentos, 58 miles from Higueritas, the first islands appear within the lake; and, their number soon increasing, we enter the delta of the Uruguay, which for 25 miles more retains the width of the lower lake, breaking, however, up into a great number of large and small islands, until, a little below Paysandu, the river proper commences within a confined channel. At Paysandu, a commercial town of importance, 125 miles from Higueritas, the delta of the Uruguay commences. At Fray Bentos the visible delta terminates; and from the latter place to the La Plata the future delta of the Uruguay is now in course of formation. . . . .

. . . . During the survey of the Uruguay there was a periodical rise of the river, viz., on February 3, 1871, and a sample of water was taken on that day at the Salto section, about 200 miles above Higueritas. The water was turbid, of deep brown color; and the analysis of the sample showed that it contained one part by weight of solid matter in suspension in 9524 parts of water. There was no perceptible change in the color of the water or in its analysis, until we reached Fray Bentos [142 miles below Salto] on the 5th February, 1871, and here it contained 1 part solid matter in 11,200 of water by weight in suspension. At Higueritas, on the same day, the waters of the Uruguay ap-

[1] Hydraulics of Great Rivers. J. J. Revy, pp. 134–135.

peared clear, and we could only trace one part of solid matter held in suspension by 25,925 of water. Nothing could more forcibly illustrate the formation of deltas. The river retains matter held in suspension by its water within its ordinary channel as long as its velocity is maintained; as soon as it enters a lake or an estuary checking regular currents, the matter held in suspension is dropped."

That is to say, in flowing 142 miles in its navigable channel and through its delta the river dropped about 15 per cent. of the load which it bore at Salto; and beyond the delta in still water it dropped 48 per cent. more; leaving it but 37 per cent. of the original load to be carried past Higueritas to the estuary of the La Plata. Or stating the proportions in terms of the sediment brought through the delta to the head of the lake, 57 per cent. was deposited and 43 per cent. escaped. It would be desirable to determine in what ratio the deposit is made in the upper and lower reaches of the lake, but Revy gives no data between Fray Bentos and Higueritas. He states however that the lake is without islands, although it is shallow with the exception of a deep channel half a mile wide; but just above Fray Bentos islands indicate the present front of the delta. The occurrence of these advance elements of the delta only in a limited distance indicates that the bulk of deposition is on the delta's front, and that the sediment which passes beyond is that which the slower current of the lake can hold in suspension.

The deposits of the extinct lakes Bonneville and Lahontan have been fully described by Gilbert and Russell, but the lake beds of the west still present rich fields for study of deposition under simple conditions in fresh and salt water.

(*c*) *Alterations of Current.*—When a land-locked water body is open to the ocean it is subject to influx and reflux of tides, but the rivers pouring into it may possess volume sufficient to exclude salt water; it is then a fresh-water estuary, which receives the sediments as well as the waters of its tributaries. The currents in such an estuary are periodic, changing with the flood and ebb, and the conditions of deposition vary accordingly. The

Atlantic coast is fringed with estuaries which are carefully mapped by the Coast Survey, but variations of deposit with changes of current have apparently not been described. Writing of the La Plata, an estuary 125 miles long, where the tide from the Atlantic contends with the current of the rivers Paraña and Uruguay, Revy says: [1]

"At this point, where the power of the tidal wave balances that of the rivers, there will be no current; the level of the estuary will rise slowly like that of a lake receiving supply from all round its border. It is here—where the rivers and the tidal wave contend for supremacy, each trying to establish its own current, and where for hours the power of either of them trembles in the balance without any sensible movement in any direction—that deposit copiously takes place; matter, held in suspension by the rivers as long as their currents are maintained agitating their water, is dropped as soon as they come to rest. It is here, within about 10 or 20 miles of the river's mouth that banks are most rapidly growing and islands are forming, and the ultimate result of these daily contests is invariably in favor of the rivers which slowly but steadily encroach on the estuary and ultimately annex its whole territory. The progress of the tidal wave is, however, never checked an instant, the rivers only check the currents originating with the wave. . . . . A tidal wave is never visible to the eye, and can only be conceived from observation, by a successive measurement of its dimensions, which are very large. We may, from an elevated position, see 10 or 15 miles, but a tidal wave on the La Plata is about 258 miles long. . . . .

". . . . During the second half of the tidal wave, viz., from flood to ebb when the surface of the La Plata is falling, there is much more uniformity in the directions of the currents, which for a time will be the same for the whole estuary, all tending to the Atlantic. The wave will again proceed faster in the deeper than in the shallower portions of the estuary, and will accordingly make the level fall a little faster in the deeper channels, and

[1] Op. cit. pp. 29–30.

the current will now set from shore into the estuary; the reverse of what happened with the rise of the La Plata.

"By degrees the level of the estuary will again adjust itself to mean sea-level. All the water which the tidal wave brought from the sea will now have to be returned, and in addition the whole volume which the great rivers have discharged into the estuary; and the currents will not only be stronger, but they will also last longer, of which circumstance the outline of the tidal wave bears evidence, the duration of the rise of the La Plata being about six hours, its fall continuing for about seven hours."

Revy further calls attention (page 23), to the fact that the current with a given fall of the river is swifter in deeper, slower in shallower water therefore deposit during flood-tide is more copious over shallows, and is there less liable to scouring during the ebb. It follows that the shallows become tide-flats, tide-flats are raised to rush-grown islands, and the islands unite to extend the river's banks. Thus the Parañа has filled two-thirds of the La Plata, which was 325 miles long, and the river will ultimately replace the estuary, so that the future delta will be built into the Atlantic, as that of the Mississippi extends into the Gulf.

If the sediment thus deposited consists of mingled sand and clay it will be sorted to some extent by the alternate checking and starting of currents. As with rising tide the current slows, sand will first be dropped; during the period of quiet water both sand and clay will sink together, though at unequal rates; and when the ebb restores the outward current, the surface of the latest deposit may be scoured, removing clay and leaving sand. Furthermore the swifter currents of the channel may carry clay, even though dropping sand, while the slower currents of the shallows drop both. Hence there must be a tendency toward alternation of more sandy layers with more clayey ones, and of horizontal passage of sands into clays.

Where rivers enter bays of such depth or expanse that the fresh water does not displace the salt water, other conditions than those governing estuarine deposition prevail. It is there

probable that the influence of tides is often subordinate to that of winds, of the difference of density between fresh and salt water, of mechanical and chemical reactions of salt water on sediments, and of currents prevailing along shore.

The influence of tides upon undertow, tending alternately to retard and accelerate the seaward current, may be important and may lead to alternate episodes of deposition and scouring as it does in estuaries; this is probably the case on all submerged continental platforms, and particularly where tides sweep in from a great expanse of ocean, as on the Atlantic coast of the United States. The effect, where conditions favor it, would be more regular than among the shoals and channels of an advancing delta, and the alternation of strata would be more distinct and even; it is possible that thinly interbedded strata of unlike character may be thus interpreted.

The well recognized characteristics of tidal formations are the evidences of shallow water, ripple marks, sun cracks, organic trails, etc., peculiar to sections of the shore where sediment is abundant. The strata are shales, and shaley sandstones irregularly bedded and often red. Such deposits are direct evidence that:

(1) The land from which they came presented gentle slopes and was mantled in residual formations to a distance from the sea.

(2) Since the zone of tide-flats along any shore is limited in width, if the distribution of such strata be wide, either great rivers gradually filled a shallow basin, as the Mississippi, the Amazon and Paraña have done, or the sea transgressed upon a low-level land. In the former case the land was built outward by volumes of muddy fresh water, and the deposits would be of fresh or brackish water types. In the latter case the sea prevailed and the deposits would be of marine character.

(3) Since the level of tidal deposits is near the surface of the water, and they are therefore limited in thickness, if a considerable thickness shows the characteristic marks throughout, the area of deposition subsided at a rate approximating to that of accumulation.

(4) Since tidal deposits are imperfectly sorted, they form under shelter from waves or in the presence of waves of force insufficient to handle the volume of sediment. The shelter may be a point of land before a bay or a barrier of beach sand before a lagoon; in either case clean sands and mud deposits may be contemporaneous. Or the feeble waves may be unequal to the task of sorting, because of short fetch in a narrow sea.

(*d*) *Long continued or powerful winds.*—The fall of a river determines its current, other things being constant, and therefore its transporting power. The fall near the mouth is lessened in any given stream if the level of discharge is raised, and vice versa, and the influence of tides in this respect has just been discussed. Winds may exercise a no less important influence. Revy (p. 27) describes an instance in which the effect upon the tides of a storm approaching from the east, combined with its subsequent direct effect in heaping up waters, was to raise the level of the La Plata fifty inches at ebb tide, and to reverse the current of the Paraña for a hundred miles. An extraordinary result like this is probably balanced in its effect upon deposition by the scouring which takes place when the wind changes direction, or calms, and the mass of water returns to its normal level. But the influence of long continued winds blowing periodically during certain seasons of the year must be effective in causing deposition from silt-laden rivers. Humphreys and Abbott briefly discuss the nature of winds affecting the level of the gulf at the mouth of the Mississippi, and assign an important share of the results from deposition to the influence of the southeast winds.[1]

(*e*) *Flotation of fresh water on salt.*—Fresh water is lighter than salt water, hence a river discharging into the ocean rises and spreads over the surface. The volume of the river, advancing, holds back the salt water, and the fresh water flows up an incline which is the surface of contact between the media of unlike densities. This checks the river's current and forms a

[1] Physics and Hydraulics of the Mississippi. Page 450.

vertical eddy or "dead angle," in which material rolled on the river's bottom is left and some sediment is dropped. Thus bars are formed in advance of deltas.[1] With rising tide or on shore winds the elevation of the salt water surface will increase this effect and force the zone of maximum deposition shoreward, while the reflux with the ebb or change of wind will lower the incline and assist wider distribution of sediment. Hence there is most rapid accumulation in the comparatively narrow strip of deposition during rising tide.

Flocculation in salt water.—Acids and salts in solution cause fine particles of sediment to draw together in flocculent form and therefore to settle more rapidly than they would in fresh water. W. H. Brewer states that clay which has been in suspension thirty months in fresh water had not settled out as clearly as the same clay from a solution of common salt in less than thirty minutes,[2] and he describes a number of experiments tending to show that "when a muddy river enters salt water chemical laws interfere with the purely mechanical ones. Then the rate of deposition is affected by the salt more than by the current, and velocities which would be more than sufficient to carry the finer suspended matter indefinitely, if the water were fresh, entirely fail where the water is brackish or salt. Practically it is the degree of saltiness which controls deposition."

Brewer applies this principle to a discussion of the formation of the bars of the Mississippi and concludes that the zone of maximum deposition retreats and advances as the greater or less volume of the river changes the position of the opposing salt water. It is obvious that this condition would be combined with that of the "dead angle" produced by the rise of the fresh water on salt.

The phenomena of flocculation have been attributed by Hilgard, Brewer and Barus to chemical reactions, but Milton Whitney finds a readier explanation in the forces of attraction or

[1] Humphreys and Abbott; op. cit. p. 445.

[2] Memoirs of the National Academy of Sciences, Vol. II, 1883, p. 168.

tension existing among the fine particles of a solid in suspension, which are modified by the presence of salts.[1] But whatever the conclusion may be as to the nature of the controlling law, the influence of salt water in this respect is an important cause of deposition of clays at the mouths of rivers.

(*g*) *Inequalities of depths; lee banks.*—When any volume of flowing water expands, it loses velocity and, if muddy, deposits sediment. This well recognized condition of river deposition has been considered in reference to a river entering a lake; it is equally true of an ocean current or of undertow, where the former passes from a narrow strait to the broader sea, or where either one flows from shallow into rapidly deepening water. The condition needs no explanation—it requires only illustration.

From the Atlantic the southern equatorial current sweeps past the mouth of the Amazon and Orinoco; as the Gulf stream it crosses before the Mississippi delta, and pouring out through the Straits of Florida enters the North Atlantic. From the rivers tributary to its course it receives fine sediment escaped beyond the deltas. In its passage through the Caribbean sea and the Gulf of Mexico it flows over the eastern Caribbean deep, Bartlett's deep and Sigsbee's deep, and where it leaves the Blake plateau north of the Bahamas it falls over the continental rim into ocean depths. Between these basins it traverses relatively shallow seas, whose bottoms are floored with modern limestone and green sand. These deeps of 2,500 to 3,000 fathoms and shoals at 100 to 500 fathoms are result of epeirogenic forces probably, but they are now floored with deposits which consist of the shells of pelagic organisms mingled with terrigenous silt, forming "modified pteropod ooze."[2] This deposition, if it has gone on long enough since the depression at the deeps, or fast enough to mask the details of deformation, possibly continued up to a recent time, determines the profiles of the slopes from shoal to abyss. In

[1] U. S. Dept. Agric. Weather Bull. No. 4, 1892, "Some physical properties of soils," pp. 19–23. Milton Whitney.

[2] Geologic and bathymetric maps of the Atlantic in "Three Cruises of the Blake," by Alex. Agassiz, Vol. I.

the Eastern Caribbean deep the declivities are such as would thus be determined; the northern and southern slopes between which the current flows are approximately equal and steep; the slope of the eastern side is also steep and lies at right angles to the course of the current in the position of a bank forming in the lee of a terrace, and the rise from the abyss westward in the direction of the current is relatively gradual. [1]

This basin is the one most advantageously situated to exhibit slopes of deposition. Bartlett's deep lies like a narrow cañon across the course of the current, and the small triangular basin immediately east of Yucatan, while it shows a steep slope northward in the direction of the current, presents similar declivities along its other two sides which are possibly scoured by the waters converging to pass out at the apex, the Yucatan channel. The steepest slope of the Gulf of Mexico from the 100th to the 2000th fathom line, is in the position of a lee-bank northwest of the Yucatan plateau, and the contours elsewhere are apparently modified by the scouring action of the current as it sweeps around the basin, and by terrigenous deposits from the adjacent shores and rivers. The Blake plateau, over which the Gulf stream sweeps north of the Bahamas, is clean, hard limestone, but a lee-bank of mud and ooze is forming on its short, steep slope into deep water. Agassiz says (p. 277): "There we pass from the comparatively coarse shore mud to finer and finer ooze, which becomes an impalpable silt in the deeper water beyond one or two thousand fathoms, assuming at the same time a lighter color."

Another illustration may be found in the deposits of silt which form the edge of the continental plateau off the North Atlantic coast of America. Agassiz has mapped the width of the plateau as covered with "silicious shore deposits," and examination of some of the samples of bottom in the Coast Survey office, for which opportunity has been most courteously extended to the writer, shows that the surface of the plateau is

[1] See bathymetric map opp. p. 98, "Three Cruises of the Blake."

composed of sands which are indeed fine near the eastern edge, yet are distinctly granular and incoherent. But soundings on the steep slope beyond the 100 fathom line have brought up very fine silt from the bank of which that slope is the surface, and this silt passes at its foot into globigerina ooze. The zone of transition from clean sand to silt is as sharp as the edge of the slope and is coincident with it. It is evident that the suspended mud which escapes beyond the estuaries and sounds of the littoral is swept out until the undertow expands over the edge of the escarpment, and is diffused in deep water; there the silt forms a great bank 10,000 feet high, with a slope of 3 to 8 degrees, which has grown seaward during geological ages, and continues to expand as erosion continues on the land.

The structure of this deposit can only be inferred, but it is worthy of consideration. The surface of accumulation, to which bedding planes are probably parallel, is inclined at a considerable angle, and traverses the bank from top to bottom obliquely to the vertical thickness. The direction of the growth is outward, not upward. The conditions of deposition are similar to those of a delta advancing into fresh water, and the structure of the deposit is probably similar to that shown by Gilbert for a fresh-water delta. (Fig. 14, p. 68, Lake Bonneville). If the detritus was sand, instead of silt, the conditions would be identical, and the bedding which would be exposed by removal of the horizontal upper layers would represent an enormous thickness of strata, inclined at a dip corresponding to the slope of the bank. Russell rejects explanations of the attitude of the Newark beds so far as they are founded on sedimentation,[1] but it seems possible that they may present the structure of lee banks. It may also be probable that isoclinal structure, where repetition of strata does not occur, is evidence of this form of deposition and of the conditions essential to it.

Deposits of this character, consisting usually of clay or silt, are significant of extended rock decay on the land, of currents

[1] Bull. U. S. G. S. No. 85, Correlation Papers.—The Newark System, p. 78. I. C. Russell.

capable of distributing the sediment, and of shoals and deeps in the sea. The amount of difference in depths is not indicated, but the rapid descent from the edge of the bank to the foot is essential to diffusion of the current and the consequent deposition. A lee-bank is a submarine terrace of construction. Where such a terrace extends into an abyss it argues prolonged development, and, therefore, antiquity of relation between continental platform and oceanic basin.

(*h*) *Subsidence from oceanic circulation.*—The greater part of terrigenous sediment must be deposited in deltas and estuaries, on continental platforms, and in silt banks along great deeps. But a very considerable amount of fine silt brought out by rivers and undertow, quantities of volcanic dust fallen on the ocean, and the calcareous and silicious parts of pelagic organisms are taken into oceanic circulation, and find a resting-place more or less remote from their place of origin. These deposits constitute the deep-sea formations; they are not clearly recognized among the strata of past geological periods now exposed in land surfaces, and on this fact rests the principal argument for the antiquity of the continents and oceans. They have been fully described by Murray,[1] and their mode of deposition need here be indicated only by reference to the blue muds of the Bay of Bengal and the Arabian Sea.

The blue muds are composed of minute mineral fragments derived from the disintegration of the land, of a diameter of .05 mm., or less, which may contain calcareous remains amounting to 50 per cent. of the whole, or may be almost free from lime. The description of a typical sample, taken about 275 miles south of the mouth of the Ganges, is given by Murray[2] in an article which is accompanied by a map showing the distribution of different formations. From this map we may gather that terrigenous deposits form a belt, 50 to 125 miles wide, along the eastern coast of Africa, the western coast of Australia, and the Malay

[1] Challenger Reports; Narr. of the Cruise, Vol. I, Part II.

[2] Scott. Geog. Mag., Vol. V, No. 8, Aug., 1889, p. 420. John Murray on "Marine Deposits in the Indian, Southern and Antarctic Oceans."

archipelago, but in the Arabian Sea and the Bay of Bengal they extend to distances of 800 miles from the mouth of the Indus and Ganges, and cover areas of more than 700,000 and 900,000 square miles, respectively. By reference to a map of the ocean currents it may be seen that their courses affect the distribution of these deposits. Sweeping at all seasons past the west coast of Australia and directly toward the east coast of Africa, parallel to which it then diverges, the principal current prevents any extended distribution of sediments in a direction normal to these coasts. But the currents of the Arabian Sea and the Bay of Bengal, flowing alternately east and west around these great embayments, past the mouths of the two great silt-bearing rivers, distribute fine material in suspension throughout the area of their circulation.

CHEMICAL DEPOSITION.

Favorable conditions:

(*a*) Evaporation from an enclosed sea.

(*b*) Precipitation of lime and magnesia from ocean waters, charged by solution from the land, through evaporation, through reaction of salt water on fresh, and through varying atmospheric conditions at the surface of the sea.

(*a*) *Evaporation of an enclosed sea.*—When a limited body of water, such as a lake, is subjected to a change of climate, so that evaporation exceeds precipitation of rain, the volume will shrink, outflow will cease, and the solution of salt will be concentrated. If the process is sufficiently continued the solution will become saturated, first for one salt, then another, and they will be deposited in the order of their insolubility. This process is important as an indication of climatic variation in the past; it has been fully described by Gilbert, Russell and Chatard for Pleistocene lakes and the chemical relations, and these studies suggest the conditions to which appeal must be made to explain the less exact facts known in ancient formations of the kind.

(*b*) *Precipitation from brackish waters.*—The chemical precipitation of lime and magnesia from sea-water is a much mooted question. There are two lines of evidence relating to it which

are apparently opposed. On the one hand, the scientists who have described material obtained by soundings on modern limestone deposits have recognized only organic remains. The Challenger in the open oceans, remote from great rivers, the Coast Survey vessels in the Caribbean, the Gulf of Mexico and off the Atlantic coast, the Norwegian expedition in the North Atlantic and English vessels in the Indian ocean have found calcareous oozes of various kinds and rocky limestone formations, but in every case the calcareous matter is described as composed wholly of the tests of pelagic organisms, many of them of microscopic size. It is known that carbonates of lime and magnesia are to a greater or less extent soluble in waters containing carbonic acid, and that the proportion of these carbonates dissolved in ocean waters is small. According to Dittmar the salts in solution in ocean waters contain 0.345 per cent of carbonate of lime and 3.600 per cent of sulphate of lime,[1] and the ocean is capable of dissolving all the lime poured into it by rivers.[2] This view being accepted, it follows that pelagic organisms, which possess the power of secreting solid carbonate of lime from solution, alone can cause lime deposits. Chemical precipitation is, according to this view, impossible, or, if it occurs, is followed by speedy re-solution, and all limestones deposited under conditions of the existing oceans are of organic origin. On the other hand, there are many limestones, deposited at different periods of geologic time, from Algonkian to the present, including some now forming, which consist of more or less clearly crystalline calcite, devoid of organic structure. If this calcite was originally built into organic forms they have been entirely obliterated. Such limestones do indeed contain fossils which sometimes exhibit more or less crystalline texture, but the occurrence of these organic forms in the holocrystalline matrix only raises the question: If the mass was originally all organic and has undergone secondary crystallization after lithifaction, why was the process so complete in the matrix

[1] Report on the Scientific Results of the Voyage of H. M. S. Challenger. "Physics and Chemistry." Vol. 1, p. 204.

[2] Op. cit. p. 221.

and relatively so ineffective in structures whose delicate anatomy can still be traced even to microscopic details? Thin sections of limestone which show a mass of interferant crystals suggest that this was the primary structure of the rock, and organic remains appear to be foreign bodies which are accidentally of the same substance as the matrix. If this view be correct, then only the alteration of the organic carbonate is the measure of the alteration of the rock-mass. If it can be shown that limestones now forming by chemical precipitation possess a crystalline structure, which resembles that of ancient limestones, the resemblance will constitute a presumption in favor of similarity of origin for the modern and ancient formations. And the fact that limestone is now being precipitated would, if it be established, leave the geologist free to weigh the evidence in the case of any ancient limestone for and against its organic or chemical origin. It is not proposed here to argue that limestones are prevailingly of one origin or the other, but only to show that the assumption of organic origin for all the calcareous deposits of the stratified series is too sweeping. To this end it is desirable to consider the chemical and mechanical conditions which affect the precipitation of carbonate of lime, to estimate the solubility of the carbonate in salt water, to review the conditions under which lime is contributed to, and distributed in, the sea, and to describe several cases of modern limestone formation by precipitation.

Schloesing made a number of experiments on the solubility of carbonate of lime in carbonic acid and water; he thus describes his method and results.[1]

"Experiments:—The method adopted was to cause to pass through pure water, which was maintained at a constant temperature and contained an excess of carbonate of lime, a mixture of air and carbonic acid, of a composition varied at will, but constant, for each experiment; this mixture was constantly supplied until a perfect equilibrium was established between the substances

[1] Comptes Rendus, Vol. 74, 1872, pp. 1552-56, and Vol. 75, p. 70.

entering into the reaction, then the quantities of carbonic acid and of lime were determined in the filtered solution.

"Then to run through the scale of pressures of the carbonic acid from the most feeble to the strongest that could be obtained.

"Then to change the temperature and re-commence anew the series of experiments in order to eliminate the influence of heat.

"The experiments establish the fact that pure water in the presence of carbonate of lime, and of an atmosphere containing a determined proportion of carbonic acid, dissolves simultaneously free carbonic acid according to the law of absorption of gases, neutral carbonate according to the solubility of this salt in water free from carbonic acid, and bicarbonate of lime."

The relation found between the tension of the carbonic acid and the proportion of bicarbonate formed is such that: "Equilibrium being established in the solution, the slightest diminution of the tension of the carbonic acid in the atmosphere determined the decomposition of a corresponding quantity of bicarbonate, with precipitation of the neutral carbonate and the emission of carbonic acid gas."

The veteran chemist Dumas, in an article on the normal carbonic acid of the atmosphere, says:[1]

"In recent times, by a happy application of the principle of dissociation, M. Schloesing has shown that the proportion of carbonic acid contained in the air was in relation with that of bicarbonate of lime held in solution in the waters of the sea. When the amount of carbonic acid (in the air) is diminished the bicarbonate of the lime in the sea is dissociated, the half of its carbonic acid passes into the air, and the neutral carbonate of lime is precipitated from solution" ("deposé").

Another condition which may decompose bicarbonate of lime is simple mechanical agitation of the water holding it in solution. Dittmar in examining samples of ocean water for car-

[1] Comptes Rendus, Vol. 94, 1882, p. 70.

bonic acid, was led to make a series of experiments on the effect of shaking with air an artificial sea-water, containing a known amount of carbonic acid. He found that he shook out 27 per cent of the carbonic acid originally present, and this did not represent the greatest possible loss. After describing the experiments he says :[1]

"The experiments reported in this chapter . . . are sufficient to prove . . . that, supposing a sea-water which contains its carbonic acid as bicarbonate, associated or not with free carbonic acid, to be exposed to the air even at ordinary temperature, such a water will soon lose not only its free but part at least of the loose carbonic acid of the bicarbonate (*i. e.*, of what is present over and above that existing in the form of normal carbonates)." Dittmar also discusses the dissociation tension of bicarbonates in sea-water and suggests that the water of the tropics constantly gives out carbonic acid to the air, and water of cooler and of arctic zones constantly absorbs it.[2]

Thus the chemists describe two conditions under which bicarbonate of lime may be decomposed into neutral carbonate and carbonic acid: 1st, by diminution of the tension of the carbonic acid in the atmosphere; 2d, by agitation of the solution.

Theoretically, either one of three things may occur to the neutral carbonate of lime if it be thrown out of solution by either one of these processes, which we may admit are active on some portions of the salt water surface. The carbonate may be redissolved, or deposited as a calcareous mud, or built into organic structures. We may discuss these alternatives in turn.

The solvent action of sea-water has been the subject of direct observation in the ocean and of experimental determination. Deep-sea shells, dredged from the bottom of the Pacific and now in the Smithsonian collection[3] are corroded, some of them on the outside only, some of them through and through. In the former

[1] Report on the Scientific Results of the Voyage of H. M. S. Challenger. "Physics and Chemistry," Prof. Wm. Dittmar, F. R. S. Vol. I, p. 115.

[2] Op. cit., pp. 212-213.

[3] For an opportunity to examine these my thanks are due to Dr. Dall, B. W.

case the creature still inhabited the shell and preserved the essential parts of its house; in the latter case the decomposition of the fleshy parts may have assisted the solution of the calcareous skeletons. To this last point Murray calls attention:[1]

"It is probable, however, that carbonic acid does play an important part in the solution of shells of animals sinking through the water. The organic matter of the animal on being oxidized produces carbonic acid, which, being itself liquid at all depths over 200 fathoms, will form a locally concentrated acid solution inside the shell, which it will attack with vigor."

The shells which were corroded while still inhabited were also exposed to unusually active solvent influences since they lay upon the bottom, of which Agassiz writes:[2]

"The pelagic animals derive a large part of their food supply from the swarms of large and small pelagic algæ covering the surface of the sea in all oceans. On dying, both surface animals and plants drop to the bottom, and still retain an amount of nutritive matter sufficient to serve as food for the carnivorous animals living on the bottom. A sort of broth, as it has been called by Carpenter, collects on the bottom of the ocean, and probably remains serviceable for quite a period of time; the decomposition of the organic material which has found its way to the bottom takes place gradually, and its putrefaction must be very slow." Thus these more or less corroded shells, dredged from the deep sea, bear witness to the solvent evolved in a bottom layer of decomposing organic matter.

A more direct line of evidence as to the solvent action of the sea-water itself is afforded by observations on the depths to which calcareous skeletons will sink undissolved. The pelagic pteropods and foraminifera, living at the surface, sink on dying and are slowly dissolved; if the water be too deep they never reach bottom. The limits below which they are not found are about 1500 fathoms for pteropods, thin shells exposing large

[1] Narrative of the Cruise of the Challenger, Vol. I, Second part, p. 981.

[2] Three Cruises of the Blake, Vol. I, p. 313.

surfaces to solution, and 2800 for globigerina, smaller shells, relatively more massive. Commenting on this, Dittmar says:[1]

"At the greatest depths of the oceans all these calcareous shells disappear from deposits in all latitudes. The cause of this, in my opinion, is not that deep-sea water contains any abnormal proportion of loose or free carbonic acid, but the fact that even alkaline sea-water, if given sufficient time, will take up carbonate of lime in addition to what it contains."

The solvent action indicated by the disappearance of delicate and microscopic shells, which enclose decaying organic matter, yet sink through 9000 to 16,000 feet of water, is very moderate.

Dittmar says:[2] "Sea-water is alkaline; all the alkalinity must be owing to carbonates, and of these carbonate of lime is one." Now the very moderate solvent power of this alkaline solution may be satisfied so far as carbonate of lime is concerned by two sources—by organic tests in suspension, and by chemical precipitate. The lime used by organisms is derived from the solution to which it is partly returned by re-solution, but another part is deposited, and the sea thus suffers constant loss. This loss is supplied by the land. If this terrigenous supply is less than the amount of organic deposit the sea will become less alkaline, and will more efficiently dissolve calcareous tests until the solvent is satisfied. If the land contribution is continuously equal to the amount organically subtracted, there will be equilibrium. If the land yields more carbonate of lime than that which is being locked up in organic limestones, the alkalinity of the sea will gradually increase until there is chemical precipitation. This condition is favored by the entrance of lime-bearing fresh water into a sea free from active currents and exposed to evaporation which balances the inflow.

Since the amount of lime in the ocean is thus balanced between that contributed by the land, and that precipitated by organic or chemical means, it is worth while to review the con-

[1] Op. cit., p. 221.

[2] Op. cit., p. 206.

ditions under which lime is carried from the land, and to consider how it is distributed in the sea. As was stated early in this paper, the amount of lime carried annually from a given land area is directly related to the efficiency of rock-decay; rock-decay is most efficient over surfaces which have suffered prolonged degradation, and on such surfaces the development of drainage systems has usually resulted in the growth of great rivers. Hence the lime contributed from continents to oceans is delivered chiefly at a few places, the mouths of extended systems, and there is great inequality in the distribution of these along different coasts and among different seas. Of this fact South America is the most conspicuous example, with all its great rivers pouring into the Atlantic, and not one considerable stream entering the Pacific. More limited seas, which receive vast quantities of solutions are the Caribbean and Gulf of Mexico, Arabian Sea, Bay of Bengal and Yellow Sea.

At the mouths of great rivers there exist several conditions which influence the solubility and distribution of lime in the adjacent seas; these are: 1st, the amount of lime in solution in the river water; 2d, chemical reactions between substances in fresh and salt water; 3d, the relative solubility of lime in fresh and salt water; 4th, the conditions of evaporation and agitation of the brackish water; 5th, the effects of currents.

The proportion of solids in solution in a river is dependent not only on the extent and slopes of its basin, but also on the nature of the rocks exposed, and the influence of climate on decay. Under like topographic conditions, silicious schists and a cold climate probably yield a minimum contribution; crystalline rocks and a warm, moist climate yield more; limestone areas, though resistant in a dry climate, suffer most rapid degradation under a humid atmosphere, and the deposits of the later geologic periods, including as they often do quantities of soluble salts, charge the drainage most strongly. The following analyses present specific contrasts, traceable to these geologic and climatic conditions. Each analysis represents but one phase of composition, which varies in each river with high and low

stages, and the analyses of our great rivers are incomplete, but, strange as it seems, no other analyses of their waters have been found, after diligent search.

SAMPLES.

(*a*) Ottawa river; sampled March 9, 1854, before the melting of the snow, at head of St. Anne lock; water was pale amber yellow, free from sediment and derived from a region of crystalline rocks covered with forest and marsh vegetation.[1]

(*b*) St. Lawrence river, sampled March 30, 1854, before the melting of the snow, on the south side of the Pointe des Cascades, Vaudreuil; water was clear, colorless, and represents the drainage of areas of glacial drift, crystalline rocks and paleozoic sediments, clarified by passage through great lakes.[1]

(*c*) Mississippi river;* sampled in the autumn of 1887 at very low water, in the main channel above the mouth of the Missouri; water represents drainage from areas of glacial drift, crystalline rocks and paleozoic sediments, including large expanse of limestone and cultivated lands.

(*d*) Missouri river;* sampled on the same day as the preceding; water represents drainage most highly charged with the soluble salts of the more recent and little consolidated geologic formations; potash was no doubt present but was not determined.

(*e*) Mississippi river;* six miles below the mouth of the Missouri; sampled on the same day as the preceding in the current of Mississippi water as shown by a float dropped on taking sample *c;* sample represents Mississippi and Missouri waters, apparently with excess of the latter.

(*f*) Mississippi river;* twelve miles below the mouth of the Missouri, above St. Louis; sampled on the same day as the preceding in the current indicated by the float; sample represents Mississippi and Missouri waters apparently more thoroughly mixed.

[1] Geology of Canada, 1843-63, Logan, pp. 565-568.

*Annual Report of the Water Commissioner, St. Louis, 1888, pp. 309-310. Analyses by St. Louis Sampling and Testing Works, Wm. B. Potter, Manager.

ANALYSES—PARTS PER 1,000,000 OF WATER.

Constituents.	Ottawa. *a*	St. Lawrence. *b*	Mississippi. *c*	Missouri. *d*	Missouri and Mississippi. *e*	Missouri and Mississippi. *f*
Total Solids	------	------	253.69	1207.66	1058.98	787.12
Filtered sediment	69.75	167.80	20.90	638.26	622.33	389.36
K	1.52*	1.15*	not given	not given	not given	not given
Na	2.39*	5.03*	3.37*	12.76*	9.16*	10.37*
MgO	2.36*	12.08*	28.26	41.96	37.51	39.40
CaO	13.88*	44.92*	52.93	110.15	109.63	94.90
Cl	.76	2.42	5.31	19.53	14.22	15.93
SO_3	1.61	6.87	10.28	89.76	73.66	69.89
SiO_2	20.60	37.00	not given	not given	not given	not given
	69.75	167.80	20.90	638.26	622.33	389.36
Iron and alumina	traces	traces	none	55.84	20.90	26.80

According to Gooch[1] the combination in these analyses should be calculated in the order KCl, NaCl, K_2SO_4, Na_2SO_4, $MgSO_4$, $CaSO_4$, $MgCO_3$, $CaCO_3$ Na_2CO_3, etc.; and this is the order followed in the Canadian analyses. Hence the following is the hypothetical combination.

	a	*b*	*c*	*d*	*e*	*f*
Total Solids	-----	------	253.69	1207.66	1058.98	787.12
Filtered sediment	69.75	167.80	20.90	638.26	622.33	389.36
KCl	1.60	2.20	not given	not given	not given	not given
NaCl	-----	2.25	8.57	32.03	23.30	26.38
K_2SO_4	1.22	------	not given	not given	not given	not given
Na_2SO_4	1.88	12.29	not given	not given	not given	not given
$Mg SO_4$	none	none	15.41	125.90	118.49	104.83
$Ca SO_4$	none	none	none	9.93	none	none
$Mg CO_3$	6.96	25.37	19.63	none	1.37	4.28
$Ca CO_3$	24.80	80.83	94.56	189.35	195.79	169.47
Na_2CO_3	4.10	0.61	none	none	none	none
$Fe_2O_3 +$ Al_2O_3	traces	traces	none	55.84	20.90	26.80

The chemical reactions which take place between substances dissolved in river waters and those contained in salt water are no doubt complex; but that which is most significant in relation to possible precipitation of carbonate of lime depends upon the fact that organic matter may decompose sulphate of lime. Ac-

* Calculated from combinations given in the original publications.

[1] Analyses of Waters of the Yellowstone National Park, Bull. U. S. G. S., No. 47, p. 24.

cording to Dittmar,[1] the greater part of the lime in ocean water is there combined as sulphate, which in contact with organic matter would be reduced to sulphide with evolution of carbonic acid; the latter would attack the sulphide with formation of carbonate of lime and sulphide of hydrogen. Thus organic matter in river waters tends to increase the proportion of *carbonate* of lime in the zone of brackish water. The carbonate thus formed is added to that already existing in the river water.

The solubility of carbonate of lime in fresh water and in salt has been an object of consideration by several experimenters. Sterry Hunt testing artificial solutions found that 1 litre of water which contained 3 to 4 grams of sulphate of magnesia could dissolve 1.2 grams of carbonate of lime and 1 gram of carbonate of magnesia; but after standing a long time all the lime was deposited as hydrated carbonate.[2] Thus it would appear that the presence of the sulphate assisted the solution of the carbonates.

Experiments made by Daubrèe, which contradict Hunt's results, led Thoulet to conduct a series to determine the question.[3] He took several minerals, marble, shells, coral and globigerina ooze, and subjected the comminuted samples of each separately to the action of filtered ocean water and distilled water during five weeks in each case. The solutions were shaken several times each day and the water was changed from time to time. At the close of the experiments the samples had lost in weight and the amount taken into solution, reduced to that dissolved per cubic decimeter per day, was found to be, in grammes

	In ocean water.	In fresh water.
Shells, - - - - -	.000039	.001843
Coral, - - - - -	.000201	.003014
Globigerina, - - - -	.000137	.003091

[1] Op. cit., p. 204.

[2] Dittmar, op. cit., p. 209.

[3] Oceanographié (Statique) par M. J. Thoulet, 1890, p. 263, and Comptes Rendus, t. CVIII, April, 1889, p. 753.

"One sees that the solubility in ocean water, itself very feeble, is also notably more feeble than the solubility in fresh water."

When river water enters salt water it is exposed in different form and under different physical conditions from those which existed in the river. As the fresh water is lighter than the salt, it floats upon it and spreads out in a sheet not unlike a fan. As compared with its depth and width in the river the layer is very shallow and widens from the mouth. Through waves and currents the fresh and salt water mingle, and the expanse of brackish water may be of great extent. Forchhammer attributes the minimum salinity which he found for surface water from the north Atlantic, 900 miles from the mouth of the St. Lawrence, to the volume of that river, and he found the ocean water freshened at a similar distance from the La Plata. This thin sheet of brackish water is exposed to variations of temperature and barometric pressure produced by changing winds, now on, now off shore, and is in constant agitation with the rise and fall of waves. Thus the conditions which produce varying tension of carbonic acid, and which aid the escape thereof, exist at its surface, and the bicarbonate of lime in solution must be in unstable equilibrium, with constant formation of neutral carbonate and more or less constant recombination of it. If the neutral carbonate be present in sufficient quantity it will remain in suspension, undissolved and unused by organisms, and will ultimately be deposited as calcareous ooze.

Oceanic circulation maintains an approximately uniform composition of ocean water in all parts of the open seas, and great currents sweeping past river mouths distribute the contribution of fresh water and its solid matters, whether in solution or suspension. Thus the lime brought down by rivers, though measurable by hundreds of thousands of tons per annum, is so widely diffused in the vast volume of the ocean that it escapes recognition.

There are, however, several instances of modern limestone formation which, though local, illustrate the processes of chemical deposition on a large scale. The descriptions of these may

close these suggestions concerning limestone deposition by other than organic means.

Chemically deposited limestone is forming in the southern part of Florida, probably over extensive areas. The Everglades, 4,000 to 5,000 square miles in extent, lie nearly at sea level, margined by barrier reefs which confine the surface waters; in the dry season the drainage consists of numerous small streams—in the wet season the region is all submerged save the numerous muddy islands. Explorations on the western side, from Cape Sable north to Punta Rasa, were made by Mr. Joseph Wilcox, whose observations are stated by Dall as follows:[1]

"At the north end of Lostman's Key (on the west coast, in about latitude 25° 30′) they entered the river of the same name and succeeded in penetrating 12 or 15 miles inland. No hard ground was seen except near the mouth of the river, and the highest land at the latter place was not over 3 feet above high tide. Wide, shallow bays, with muddy bottom, interspersed with low, muddy mangrove islets, comprise the scenery. The boat frequently grounded, and was obliged to wait for the rise of the tide. A small fresh-water stream was finally reached, the current of which had scoured a channel 4 to 6 feet deep, with a rough, hard, rock bottom, fragments of which were broken off. It consisted of large masses of Polyzoa more or less completely changed into crystalline limestone, the cavities filled with crystals of calcspar. The rock is very hard and compact."

"Allen's creek, emptying into Walaka inlet, an arm of Chukoliska bay, was also visited. At a point 8 or 10 miles east from the Gulf of Mexico the party were able to land on soft, wet soil, a little higher and drier than that at the head of Lostman's river. A third of a mile eastward from the head of the creek specimens were obtained of a few rocks which project above the soil. They presented molds of recent shells with the interior filled with calcspar, and an occasional *Pecten dislocatus* or *Ostrea virginica*, still retaining its shell structure. The cavities between the shells

[1] Bull. U. S. G. S. No. 84. Correlation Essays—"Neocene," by Wm. H. Dall, pp. 99–101 and 154.

were filled with hard, coarsely crystalline limestone. The rock was not coquina modified, but looked more like a fossilized oyster reef. It contained no corals, and was obviously Pleistocene. The rock formed the base of small islets of drier soil amid the marsh, on which islets grew pine trees. The marsh, apart from these islets, is probably entirely submerged in the rainy season."

In the bulletin referred to Dall speaks of the rock obtained by Willcox as being of organic or of partly organic and partly chemical origin, but at the time that manuscript was prepared the observations were less complete than now. In a recent letter he says: "Mr. Willcox's observations on the deposition of the flocculent mud from lime-bearing water were later than the original statement. The precipitated mud is more or less mechanically mixed with masses of the corrallia of Polyzoa and bivalve shells driven in shore by the sea, but these creatures do not live in the muddy water, but in the clearer water outside."

Through the courtesy of Dr. Dall the writer has examined specimens of this rock. It is a light cream-colored mass of crystalline calcite formed around the included fragments of shells. Under the microscope the unaltered structure of the organic fragments is strikingly different from that of the coarse holocrystalline matrix, in which it is apparent that the crystals developed in place. Were this a limestone of some past geologic period it would be concluded, on the evidence of the crystalline texture of some parts of it, that it had been metamorphosed and that the organic remains now visible had escaped the process which altered the matrix. But the observed conditions of its formation preclude the hypothesis of secondary crystallization. Apparently, the crystalline matrix is one primary product from solution, a rock formed in contact with the bottom, the calcareous mud is another, which, being precipitated in the solution, remains an incoherent sediment.

These results may perhaps be thus explained: The drainage of the peninsula contains an unusually large amount of lime, in consequence of the abundant supply of carbonic acid and other products of vegetable decay in the sub-tropical climate and

of the calcareous nature of all the rocks of Florida. In the Everglades this water is exposed in broad shallow sheets to active evaporation, agitation and variations of atmospheric temperature and pressure. Concentration of the solution and escape of carbonic acid, including some of that in the bicarbonate in solution, follow, and the neutral carbonate is produced in excess of the amount that can be retained in dissolved form. It is therefore precipitated in two forms—first, from the mass of the water as a flocculent mud ; second, from the lower layers of the water in contact with limestone as crystals forming an integral part of the solid rock.

The alternation of dry and wet seasons is accompanied by concentration and sluggish flow, alternating with dilution and flood currents. Therefore there are seasons of more active precipitation interchanging with those of more vigorous transportation and, perhaps, partial re-solution. In these latter seasons the calcareous mud is swept beyond the shallow basin where it forms, and enters as a suspended sediment into the Gulf circulation. What part, if any, is dissolved, what is deposited as mud in the lagoons along the coast, and what is swept into the silt banks of the Atlantic, is not known.

Conditions which produced similar results are described by Gilbert as having existed in Lake Bonneville.[1] Tufa was deposited on the shores of the lake at various stages, but most abundantly at the Provo stage, during which the water lingered longest at one level. The occurrences are thus described:

"The distribution of tufa along each shore is independent of the subjacent terrane. . . . . . No deposit is found in sheltered bays, and on the open coast those points least protected from the fury of the waves seem to have received the most generous coating. These characters indicate, first, that the material did not have a local origin at the shore, but was derived from the normal lake water ; second, that the surf afforded a determining condition of deposition."

[1] Monographs of the U. S. G. S. Vol. I, p. 167-168.

Dittmar's experiments in decomposing bicarbonate of lime by agitation indicate the nature of the condition afforded by the surf, and it appears that the neutral carbonate is capable of lithifying at the point of, and immediately upon, separation. Gilbert also says that: "Calcareous matter constitutes an important part of the fine sediment of the lake bottom, and this was chiefly or wholly precipitated from solution," and to explain the formation of the coherent and incoherent deposits of the same material from the same water he suggests that "separation was promoted by aëration of the water. All precipitation being initiated at the surface during storms, coalescence at the shore may have resulted from contact at the instant of separation."

Mr. Gilbert states (pp. 178-179), that the concentration of the waters of Lake Bonneville at the Provo stage is not definitely known. The lake had an outlet at the northern end of Cache bay, and the principal tributary, Bear river, emptied into this bay near the outlet. Cache bay was connected with the main body of the lake only by a deep but narrow strait, and it is possible that evaporation from the greater expanse of the lake exceeded the inflow of fresh water into it, while the overflow at the outlet was supplied by Bear river. In that case there would have been circulation through the strait between Cache bay and the main body, an upper current from Cache bay and an undercurrent from the lake. The straits were the scene of peculiarly copious deposition of tufa.

The tufa deposited in Lake Bonneville is of the variety described by Russell as "lithoid tufa,"[1] "of a compact and stony structure" and he concludes that it was formed when the lake waters were moderately concentrated (pp. 210-222). A limestone of similar structure is now forming on the shores of Florida, where the waves break on the beaches under conditions quite like those which determine the growth of tufa, where the surf dashed against the shores of Lake Bonneville. This rock is deposited in irregular layers, sometimes three or four feet thick, on the quart-

[1] "Geological History of Lake Lahontan," p. 190.

zose beach sands. Like the tufa, it is independent of the material upon which it gathers, but the possibility of a local supply of lime exists in the discharge of surface waters below low tide. Under the microscope the material shows a dense, fine-grained groundmass of lime with admixture of fine clay, including grains of quartz and cavities filled with coarsely crystalline calcite.

A case, which is probably more typical of what may occur now, or may have occurred in past ages at the mouths of rivers and in shallow seas, is that of the limestone deposited beyond the delta of the Rhone. This is referred to by Thoulet,[1] and is described by Lyell,[2] who says: "In the museum at Montpelier is a cannon taken up from the sea near the mouth of the river, imbedded in crystalline calcareous rock. Large masses also are continually taken up of an arenaceous rock, cemented by calcareous matter, including multitudes of broken shells of recent species." Lyell attributes the precipitation of lime to evaporation of the Rhone water, which, when it is spread upon the salt water, he compares to a lake. But this one cause is no doubt combined with the chemical and mechanical conditions which have been suggested in the preceding discussion. These conditions are favored at the mouth of the Rhone by the salinity of the Mediterranean and the absence of strong currents.

The examination of a few thin sections of limestone of different ages, from Cambrian to the present, shows that they have three principal types of structure. There are those which resemble the Everglades limestone in that they consist of more or less coarsely crystalline calcite, yet include unaltered organic remains. Of these the Trenton limestone and the marbles of corresponding age in Tennessee, which occur interstratified with unaltered calcareous shales, are the most striking examples examined. Cambrian limestones and the Knox dolomite show similar crystalline structure. The second type, the precipitated sediment which forms the muds of the Everglades and which was deposited in Lake Bonneville is represented by specimens

[1] Op. cit., p. 270.

[2] Principles of Geology, Vol. I, p. 426.

composed of exceedingly fine grained, apparently pulverulent, material; the best of these are from the Knox dolomite and the Solenhofen lithographic stone. The third variety of limestone consists of the thoroughly crystalline marbles, which contain no unaltered material, and which occur in such field relations that they are known to be completely metamorphosed. Extended study is required to determine the nature of deposition of the first and second types. They may have been organic and have suffered moderate alteration only, but there is a reasonable presumption that they did to some extent crystallize in place from sea-water, and were, to a still greater extent, precipitated from the outspread fans of fresh water, radiating from rivers' mouths, whence they spread as fine silt over the bottom of the sea.

ORGANIC DEPOSITION.

Since deposits of this character are composed chiefly of the calcareous or silicious remains of marine organisms, their formation is conditioned primarily by the circumstances controlling marine life, and secondarily by the insolubility of the skeletons under circumstances of wide distribution and gradual sinking.

Favorable conditions.—(*a*) Warm waters.

(*b*) Clear waters.
(*c*) Abundant food supply.
} Conditions favorable to life.

(*d*) Depths less than 1500 fathoms.

(*e*) Expansion and diffusion of currents in rapidly deepening water.

For a description of the oceanic deposits and of the biological conditions which promote their accumulation, the reader may be referred to the Narrative of the Challenger Expedition, Vol. I, second part, pages 915 to 926. The oozes which are characterized by the predominance of remains of globigerina, pteropods, diatoms or radiolaria are there described, and it is shown that the nature of the deposit is determined by the conditions of temperature, light and motion which favor the generation of multitudes of the minute creatures whose living forms swarm at the

surface of the sea, and whose remains only enter into deposits when they have escaped being used by other creatures, or being dissolved in the ocean waters.

Agassiz, writing of the physiology of deep sea life,[1] points out that in marine, as in terrestrial, life the primary source of food for animals is in plants. The lower types of marine life, it would seem, must derive their sustenance from the water, as land plants get theirs in part from the air, and the silica and lime thus absorbed is taken directly from solution; but the creatures which live on these forms, and the carnivorous animals that feed on them, may get their lime and silica at second hand by digesting and assimilating that which the lower types take from solution. Thus the solids built from solution into organic tests may go through numberless changes before they come to rest on the bottom.

Without pursuing the discussion of biological conditions favorable or unfavorable to deposition, and without entering upon the question of coral formations, which are rarely of prominent interest in stratified deposits, the writer wishes to consider only the circumstances of limestone formation from organic remains, as that from chemical precipitates has been considered.

In discussing the solubility of shells in sea-water it has been pointed out that the layer of organic matter which accumulates at the sea bottom contains a solvent formed by the evolution of carbonic acid in the process of decay. Through this layer all substances must pass before they can become part of a lithified stratum; if they are plant tissue or flesh they will become more or less oxidized; if they are calcareous tests they will be more or less completely dissolved, and, if there be any chemically precipitated lime, arriving on the sea bottom it, too, would be dissolved in this menstruum. The earlier forms of dredge which scooped into the sea bottom, brought up a mass of ooze, formed of fine particles, burying organic forms. The later forms of dredge, arranged to skim the surface of the bottom, bring up

[1] Op. cit., pp. 312–313.

shells and organisms remarkably free from mud. Now it may be conceived that the layer of mud on which the creatures live, die, and with sunken organic remains decay, grades from the fresh surface of recent accumulations downward into a much more completely decayed and dissolved mass, and that this rests upon a surface of limestone. In the upper part of this unconsolidated stratum carbonic acid may most abundantly be evolved; in its lowest part the more concentrated solution of lime may accumulate. Then it is conceivable that lithifaction by crystallization of the carbonate of lime from the more concentrated solution is constantly proceeding on the limestone surface. If this conception be correct the formation of limestone by organic means involves the re-solution and crystallization of more or less of the calcite in the primary formation, and only those organic forms can remain unchanged which resist the solvent action. If they are delicate, as the trilobites' branchia from the Trenton limestones, described by Walcott, they give evidence that they were rapidly buried and protected.

It is thought by some that limestones are evidences of organic life at whatever period of sedimentary history they were deposited, but it has here been shown that the source of all lime in the sea is the land, and that, under conditions existing in certain localities, both crystalline limestone and calcareous mud are now forming chemically. It has also been shown that lime converted into organic forms is subtracted from that which would otherwise go to saturate the sea-water. If, then, in any early age of the earth's history, lime-using organisms were not present to subtract and deposit lime from sea-water, and if the atmospheric agencies worked then as now, the contributions from the land must have continually added to the alkalinity of the sea until chemical precipitation occurred. Such a process must have been limited to seas rather than extended to oceans, because the conditions of delivery of lime from the land were then, as now, localized. With the development of marine life and the increased demand for lime for organic use, and with the corresponding deposition of organic limestone, the sea-water must have become

less alkaline and the conditions of chemical precipitation must have been still more restricted. In time it might occur that pelagic organisms should demand so much lime for circulation from the water to calcareous algæ, to herbivorous and then to carnivorous forms, and so back into solution, that lime could escape from solution by precipitation only under exceptional conditions. If it be true that the oceanic oozes, the muds of the Caribbean, the mud-flats of Florida, and similar calcareous deposits in different seas the world over, be wholly organic, then marine life has locked up more lime than the continents could concurrently supply, and the balance is now turned against chemical precipitation. But it has not always been so.

BAILEY WILLIS.

EDITORIAL.

IN AN article on "Englacial Drift," in the July number of the American Geologist, my friend, Mr. Warren Upham, referring to my article in the first number of this Journal on the Englacial Drift of the Mississippi Basin, takes exception to the impression conveyed respecting his views in the matter of rising glacial currents. The present writer, he says, "several times speaks of the opinions of writers who believe in the considerable volume of the englacial drift, as if they supposed the glacial currents to move gradually upward from the ground to the ice surface. Such a supposition, however, seems to me quite untenable. Instead, in my own writings and those of most, if not all, of these authors, the exposure of the drift on the surface of the ice-sheet near its border, whence much of it was washed away to form the eskers, kames, and valley drift, is ascribed wholly to the superficial melting of the ice sheet, which is called ablation." I very much regret to have given expression, or to have seemed to have given expression, to the views of these writers in any other terms than they would themselves have chosen, and I cheerfully reproduce the corrective statement which Mr. Upham makes. Until my attention was called to the matter, no other interpretation of the views of these writers than that the supposed rising glacial currents moved on gradually to the surface of the ice occurred to me as possible, as no logical stopping place short of that suggested itself. I do not see any other consistent view now, but that does not affect the obligation to present accurately the views actually held. I hope these writers will credit me with attributing to them what seemed to be the most logical aspect of the hypothesis entertained by them. The supposed upward movement is attributed to differential motion

between the successive layers of ice, as stated by Mr. Upham on pages 38-9 of the article referred to (quoted below). This differential motion arises from friction at the bottom and extends to the summit. It was natural, therefore, to take it for granted that the supposed rising current extended as far as its postulated cause. It was to be assumed, of course, that the current would rise less rapidly in the upper part if the difference of movement of successive ice layers were less there than below, but it would seem that the rise must be supposed to continue *at some rate* so long as the differential motion continued, *i. e.*, until the surface was reached. The accession of snow-fall within the zone of accumulation would, to be sure, prevent erratics from reaching the new surface thus continually formed, but it would not prevent their reaching the surface in the zone of wastage. It is this latter zone with which our problems of deposition and many of our problems of derivation have chiefly to do. The career of some erratics is wholly confined to it. It goes without saying that ablation brings the surface down and is a factor in every exposure within the zone of wastage, but this does not prevent the erratics rising (by hypothesis) until they meet it. This conception of rising currents met by a plane of ablation I supposed without question to be that entertained by Mr. Upham and others. To be sure, in a strict and complete statement under this view the exposure of englacial erratics at the surface would be attributed to the joint result of the upward movement and the downward melting, but the liberties of brief and convenient statement would permit it to be referred to in terms of either factor, and I have interpreted the expressions of these writers on this basis. The correction does not, so far as I can see, in any serious way affect the main question under discussion. If there were rising currents bearing erratics to heights of 500 or 1000 feet above the base of the ice the result in ultimate deposition would be essentially the same as if the currents rose to the surface. If the rising currents are a misinterpretation, it is immaterial whether they be supposed to bear erratics to varying heights up to 500 or 1000 feet, whence these erratics move forward parallel with the base of the

ice, or whether they be supposed to continue to rise (more and more slowly) till they meet the descending plane of ablation.

If currents rise by reason of differential movements to certain heights, but not beyond them, notwithstanding the extension of the differential movements all the way up to the surface, a very distinct statement of this limitation and of the dynamics involved, qualitative and quantitative, would be appropriate. Perhaps such an explanation is intended in the following quotation from Mr. Upham, which I introduce to give ampler expression to his views, though I dissent from his interpretations of the crevasses of the alpine glaciers and of the esker, Bird's Hill, as well as from his fundamental proposition.

"The conditions of the flowing ice which seem to me to have been efficacious to carry drift upward into it from tracts of plane or only moderately undulating contour, were the more rapid onflow of the ice-sheet in its upper and central parts and even in the portion near the ground but not in contact with it, than upon the bed of the ice-sheet where its movement was much retarded by friction. A very good analogy with the slowly rising currents which I believe to have existed in many portions of the base of the ice-sheet is afforded by the edges of alpine glaciers, where the crevasses extending diagonally up stream into the glacier testify that the movement of its friction-hindered border is from the side of the valley into the ice mass. But the arched surface of the glacier and the great supply of its central current prevent the drift so worn off and borne away from being carried into the axial portion of the ice stream. Similarly the steady accession to the mass of the ice-sheet over any place by onflow from its thicker central part and by the accumulating snowfall forbade the drift of the upwardly moving basal current from being carried far into the ice in comparison with its total thickness. The evidence of the esker called Bird's Hill, near Winnipeg, Manitoba, shows that much englacial drift had there been uplifted from a nearly level country to a height of more than 500

feet in the ice-sheet.[1] Probably some of the englacial drift there was as high as 1,000 feet or more in the ice, but doubtless a larger part was below than above the altitude of 500 feet; and this was on an area where the ice-sheet had attained probably a thickness of 5,000 or 6,000 feet, its lower fifth or sixth part bearing considerable enclosed drift. In like manner the outer portions of the ice-sheet, where its thickness was less, had probably at its time of culmination no englacial drift above its lower sixth or fourth or third part. Whatever boulders and other drift became incorporated in the higher portion of the zone reached by the currents flowing upward would be thence carried forward in some regions, as from the Huronian and Laurentian areas north of Lake Huron to the boulder belts in Illinois, Indiana and Ohio, described by Chamberlin[2] without intermixture with other englacial drift brought into the ice by less powerful currents on all the intervening extent, which in the case mentioned is about five hundred miles." [3]

T. C. C.

[1] Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, vol. iv., for 1888–89, pages 36–42E.

[2] "Boulder Belts distinguished from Boulder Trains—their Origin and Significance," Bulletin, G. S. A., vol. i, pp. 27–31. "The Nature of the Englacial Drift of the Mississippi Basin," Journal of Geology, vol. i, pp. 47–60.

[3] The American Geologist, vol. xii, No. 1, July, 1893, pp. 38–39.

Reviews.

Correlation Essays, Archean and Algonkian. Bulletin of the U. S. Geological Survey, No. 86. Pp. 549, 12 plates. By Charles Richard Van Hise.

In order of publication, this is the seventh of the correlation essays originally planned by the survey for the International Geological Congress of 1891. If the long delay in the appearance of the present essay is in any measure responsible for its excellence, no one will regret that it did not appear on time. This is not the first piece of good work which Professor Van Hise has done; but he has done nothing which has been of greater utility to the geological world than the present volume will prove to be.

In no department of geology has there been more rapid progress during the last decade than in the department in which Professor Van Hise is a specialist. In no department is it more difficult for those who are not specialists to follow current progress. But so successfully has Professor Van Hise written his essay that the reader will have little difficulty in knowing the present status of pre-Cambrian geology in America. He may know definitely what is definitely known, and he may know definitely what is not known. More than this, he may know definitely the limitations and imperfections of facts and principles which are but partially worked out, without finding himself confused between fact and possible fact, or between established principles and unverified hypotheses. Consciously or unconsciously, the author has given definite shape to the uncertainties and indefinitenesses of his subject, and in so doing has rendered an invaluable service to students.

A mere summary of what has been done in the various areas of pre-Cambrian rocks would be valuable. But the present essay does much more. The author is personally familiar with much of the ground brought under review in the volume, and he has given, always without a suggestion of dogmatism, what every reader is glad to have, his own opinion concerning the interpretations to be placed on the phe-

nomena of each of the regions with which he is familiar, together with the reasons therefor. The failure to summarize and interpret the summaries of the literature reviewed has lessened the value of some of the essays of this series.

The plan of the volume is simple. It consists of, first, a digest of all the papers on the pre-Cambrian geology of North America which had appeared at the time the manuscript left the author's hands; second, a discussion of the literature; and, third, a discussion of the general principles involved in the study of pre-Cambrian rocks, together with a statement of the results which have already been attained in America in the application of these principles.

The digests of the literatures are grouped on a geographical basis. The digest of all publications bearing on the pre-Cambrian geology of the original Laurentian and Huronian areas constitute one chapter, and the digests of the literature of the Lake Superior region, of the great northern area of Eastern Canada and Newfoundland, of the isolated areas in the Mississippi Valley, of the Cordilleras, and of the Eastern United States, constitute each a separate chapter. Within each area the digests are arranged chronologically. At the close of each chapter, or in some cases at the close of their subdivisions, are summaries of the results thus far attained in the respective areas. In all cases the digests appear to be as nearly absolutely impartial as it is possible for human work to be. The total number of papers summarized is between 700 and 800. Many of them are papers of considerable length, some of them being elaborate reports. When it is remembered that these papers are not roughly abstracted, but that carefully considered digests are presented, the amount of labor involved in the preparation of the bulletin will be apparent.

It is the final chapter which, together with the maps, will attract most attention. This chapter gives a concise outline history of the development of pre-Cambrian geology in America, and a clear exposition of its present status. Professor Van Hise concludes that it may be accepted as demonstrated that in North America there is an intricate system of granites and gneisses and crystalline schists, which represent the oldest rocks of the continent, and that this system underlies all known sedimentary rocks and their derivatives, and that if it ever contained sedimentary materials of any sort, all evidence of their existence has been obliterated.

It is to this system of rocks that the name Archean is restricted.

The minerals composing these rocks, wherever found, generally agree in showing evidence of extensive dynamic changes, as do also the relations of each sort of rock composing the system, to each other. So closely do the rocks of this system resemble each other in different regions, that Professor Van Hise says that a suite of specimens of Archean rocks from any one of the regions examined by him, if not labeled, "could by no possibility be asserted not to have come from any other." The system is a unit, both in its positive and negative characters.

To the Archean system thus defined are referred the basement complexes of Arizona, of the Wasatch Mountains, of certain ranges of Nevada, of Southwest Montana, of Texas, of the Lake Superior region, of the Hudson Bay region, probably the basement complex of Newfoundland, and much of the great area of Northern Canada, known as Laurentian. The basal complexes of the Front range, and of the Quartzite Mountains of Colorado, are referred to the Archean with less confidence. Still other areas not yet definitely classified may prove to be Archean in whole or in part.

With reference to the origin of the Archean, Professor Van Hise inclines to a modification of the theory that the system represents a part of the original crust of the earth. He believes that the Archean rocks were originally igneous, and that they may include not only such remnants of the pre-sedimentary crust as may exist, but those deeper parts of the crust which became lithified in later times, and which have reached the surface by denudations. He suggests that the banded and contorted granite-gneiss which serves as a background for the Archean may represent the rocks having such an origin, while the other parts of the system may be subsequent eruptives, assignable to no other system, and physically a part of the Archean.

The author does not overlook the fact that this suggestion concerning the origin of the Archean may make the system include rocks which crystallized below the outermost crust after sedimentation began, and that the date of this lithification may therefore be Algonkian, or even post-Algonkian. Their crystallization at such a date is not looked upon as sufficient reason for excluding them from the Archean group. It is manifestly impracticable to have an Algonkian system below the Archean, representing crystallization or lithification synchronous with the Algonkian sedimentation above.

This being the conception of the Archean, it is evident that strati-

graphical methods are not applicable to it. The only division which seems applicable is a bifold one, based on lithological characters and relations, viz.: 1, the more schistose rocks, generally dark colored, and 2, the more massive rocks (granites and granite-gneisses), generally light colored. To the latter class it is proposed to restrict the name Laurentian. For the former class, the coördinate name Mareniscan is proposed, the term being derived from the name of a township (Marenisco) in Michigan.

The necessity for a group between the Archean and Cambrian has come to be generally recognized during the last decade. But to all except those engaged in the study of pre-Cambrian rocks, the names which have been used to designate this group, or parts of it, have always been confusing, because of their multiplicity, their lack of definition, and the lack of uniformity in their use. This bulletin makes clear the nomenclature which has been adopted by the survey, and sets forth the relation of the various names which have been used to designate parts of the post-Archean (as here used) and pre-Cambrian group. Whether or not those not connected with the survey agree that the nomenclature officially agreed upon is the best possible, it is to be hoped that it may be uniformly adopted in the interest of intelligibility. It has the merit of simplicity and definiteness, and of avoiding disputed questions, so far as this is possible.

To the post-Archean pre-Cambrian group is given the name *Agnotozoic*, or, preferably, since its fossils are becoming known *Proterozoic*, a term coördinate with Archean, Paleozoic, etc. Since it is impossible to divide this group into systems coördinate with Cambrian, Silurian, etc., which can be correlated with each other throughout the various areas of Proterozoic rock, the term Algonkian is used for the present as a single system term to cover the whole Proterozoic group. In many areas the group is distinctly divisible into two or three systems comparable with the Cambrian, Silurian, etc. Thus in the original Huronian area there are probably two unconformable series of rocks, the lower unconformable on the Archean, and the upper unconformable below the Cambrian. These may be correlated with some degree of confidence with the Lower and Upper Huronian of the Lake Superior region. But here a third series, the Keweenawan, intervenes between the Upper Huronian and the Cambrian, and is unconformable with both. In the Grand Cañon region again, three series are recognized. But their relation to the three series of the Lake

Superior region is not known. The same is true of other regions. For this reason, the various terms, Huronian, Keweenawan, Vishnu, Chuar, etc., which have been used to designate definite parts of the group, will still be retained, for in the absence of criteria for the satisfactory correlation of the subdivisions of the group in the various regions where they occur, these parts must continue to bear local names.

The group is so extensive as to be comparable in thickness to the Paleozoic, Mesozoic and Cenozoic combined, and inferentially to represent an equal lapse of time. It contains great systems, separated by great unconformities. Concerning the two unconformities in the systems in the Lake Superior region, those between the Lower and Upper Huronian and between the latter and the Keweenawan, Professor Van Hise says: "Each represents an interval of time sufficiently long to raise the land above the sea, to fold the rocks, to carry away thousands of feet of sediments, and to depress the land again below the sea. That is, each represents an amount of time which is perhaps as long as any of the periods of depositions themselves." In parts of the region the Lower Huronian is known to be unconformable on the Archean. In other parts the relations are unknown. This statement of the case gives some idea of the thickness of the group, as well as of its complexity and importance.

The delimitation of the Algonkian is theoretically easy, after the definitions of the Archean and Cambrian. It includes all pre-Cambrian sedimentary rocks, and their igneous equivalents. Although a great unconformity generally separates the two groups, helping to render their distinction clear, it is not always easy of recognition. Locally parts of the Algonkian have undergone such profound metamorphism at the hands of dynamic forces which affected the Archean as well, that they seem to be structurally one. In such cases it is believed that the apparent conformity is in reality apparent only, the original structural relations being obscured or even obliterated by the structures superinduced by dynamic forces on both series involved. Even where there is a common structure in rocks regarded as Archean and Algonkian, there is sometimes inherent evidence that one part of the rocks concerned is clastic, while similar evidence is wanting in the other.

Not the least instructive part of the volume is the discussion of the principles applicable to Algonkian stratigraphy. It would be useless

to attempt to summarize this discussion, since it is as brief as is consistent with adequacy, in its original form. Suffice it to say that while, as applied to Paleozoic rocks, the value of lithological characters and structural relations are well understood, they have a somewhat different meaning and a greater relative value when applied to the pre-Cambrian formations. At the same time this application is more difficult.

One of the most valuable parts of the volume consists of the twelve maps, covering most of the areas where pre-Cambrian rocks are known or suspected. Nowhere else does Professor Van Hise succeed better in making the indefiniteness of our knowledge definite, than on the maps. On but two of the twelve maps does he represent Archean rocks, viz., on the maps covering the original Huronian area and its surroundings, and on the map of the Lake Superior region. Within the United States, Archean rocks are mapped in but three states — Minnesota, Wisconsin and Michigan. This does not mean that Archean rocks do not exist elsewhere, or that they are not known elsewhere, but that their areas elsewhere, so far as covered by the maps, have not been defined. Some of the areas which we have been accustomed to see represented as Archean on maps made before the Algonkian was differentiated, are now represented as "unclassified pre-Cambrian." Of this the Adirondack region may serve as an example. The maps tell us only that the rocks of this region may be Algonkian, or Archean, or both. In the text Professor Van Hise's opinion concerning the area may be found. This is to the effect that the Algonkian is certainly represented in the region, and Archean possibly, but that existing knowledge on the point is not sufficiently definite for cartographic representation. Other areas which have been mapped as Archean are represented simply as "unclassified partly or wholly crystalline rocks." Of the areas thus represented, the whole of the crystalline schist belt of the Appalachian region may serve as an example. The author's map does not even assert that these rocks, or any part of them, are pre-Cambrian. Here again we find the author's opinion in the text, where it is indicated that parts of this area are pre-Cambrian, while other extensive portions may, or may not be. Such pre-Cambrian areas as are known are not defined, and therefore cannot be represented on the maps.

Algonkian rocks find definite representation in more regions than the Archean. They appear upon the maps in Arizona, New Mexico,

Utah, South Dakota, Minnesota, Iowa, Wisconsin, and Michigan. They are known, but their areas not defined, in various other localities.

The summaries of the several chapters, or their sections, the final chapter, and the maps, should serve as a text-book on pre-Cambrian geology for all advanced students in our universities. Not only will the best information available be thus put into their hands, but the whole treatment of the subject is such as give an intelligent insight into the methods of geology, and into the methods of science as well.

ROLLIN D. SALISBURY.

Analytical Abstracts of Current Literature.

Summary of Current Pre-Cambrian North American Literature.*

Cross[1] describes a series of hornblendic, micaceous and chloritic schists, on the eastern side of the Arkansas river, near Salida, Col. In places these grade into massive rocks. They are cut by granitic and pegmatitic veins, as well as by dykes of porphyry. A detailed microscopical study leads to the conclusion that the rocks are a metamorphosed volcanic series. The whole constitutes a part of a single anticline. The schists are unconformably below the Silurian, and as the known Cambrian in Colorado is a thin series of quartzites and shales conformable with the Silurian, the Salida schists are considered as pre-Cambrian. The relations of the schists to the Archean complex are not exposed, but they are probably a continuation of the hornblende-schists of Marshall Pass. Greenish schists are found at Tin Cup Pass, and near the town of Tin Cup is a highly crystalline marble interbedded with the green schists, and fine grained gneissoid rocks, showing that metamorphosed sedimentary rocks do exist among the crystalline schists of the Sawatch Range. Taking into account all the facts it is thought that the schists and massive rocks of the Salida section probably represent a great series of surface lavas, erupted in Algonkian time.

Smyth (C. H.)[2] describes the rocks near Gouverneur, New York, as consisting of gneiss, granite, limestone, and sandstone, with small amounts of associated schists. The gneiss is the oldest rock of the region, underlying the other formations. It sometimes grades into a true granite, the passage being gradual. The two are regarded as different phases of the same rock, either the granite being an unchanged remnant of a Plutonic mass from which the gneiss is derived, or the result of fusion of the gneiss. Evidence of unconformity between the beds of the limestone and the foliation of the

*Continued from page 314.

[1] Series of Peculiar Schists near Salida, Col., by Whitman Cross. In Proceedings of Col. Scientific Soc., Jan., 1893, pp. 1–10.

[2] A Geological Reconnaissance in the vicinity of Gouverneur, by C. H. Smyth, Jr. In Transactions N. Y. Academy of Sciences, vol. xii., April, 1893, pp. 97–108.

gneiss was found in two localities, and was indicated in several others; there is no evidence of irruptive contacts between the gneiss and limestone; the gneiss shows no evidence of sedimentary origin; therefore, the simplest hypothesis, but requiring more proof, is that the gneiss is an eroded metamorphosed plutonic rock, upon which the limestone was deposited. The marble is coarsely crystalline, and in age is next to the gneiss. Near the base of the limestone, and interbedded with it, are peculiar schistose rocks, which, while completely crystalline and resembling igneous rocks in composition, are indicated by their field relations to be of sedimentary origin. Near Gouverneur an outcrop of limestone contains abundant fragments of black schist, scattered through the limestone in a most irregular manner, and making up, perhaps, one-third of the rock. This and other outcrops show that the schist fragments are remains of once continuous schist layers, which have been completely shattered in the course of metamorphism, since between the continuous belts of schist and the Gouverneur locality there is every possible gradation. While the schists show the effects of foldings, contortions, stretchings and shattering, the limestone shows no traces of it, it appearing to have been a plastic mass in which the schists moved with considerable freedom. The conspicuous result of metamorphism in the limestone is crystallization. In the limestones are also pegmatitic veins, which have been much shattered by the dynamic action, reducing them to small lumps of quartz and feldspar, scattered through the limestone. So far as observed the pegmatite yields to strain only by fracturing, not showing preliminary contortions, so general in the schistose layers.

In the southern part of the area examined is a granite, not grading into gneiss, and which breaks through the limestone, causing great disturbance in strike and dip, enclosing masses of the rock many feet in diameter, and metamorphosing this rock to some extent. The sandstone at Gouverneur was found in direct contact with the limestone. Here it appears that the limestone surface has been subjected to erosion before the sandstone was deposited upon it. In confirmation of this are seen narrow irregular cracks extending several feet into the limestone, which have been filled with sandstone. The limestone was evidently completely lithified when the sandstone was deposited and sifted into it, and this implies discordance. This unconformity proves that the limestone is older than the upper Cambrian, the data being wanting for any more definite determination of its age. The metamorphism of the rocks of the limestone-bearing series occurred before upper Cambrian time, but the sandstone is metamorphosed, and this metamorphism must therefore belong to post-Potsdam time.

Comments.—The inquiry rises whether the second metamorphism spoken of, that of the sandstone, is produced merely by interstitial cementation, or is dynamic metamorphism. If the first is found to be the explanation, so far as

the paper gives any evidence, all of the igneous activity and dynamic metamorphism are pre-Potsdam.

[1] Wadsworth gives a sketch of the iron, gold and copper districts of Michigan. The Azoic or Archean rocks are divided from the base upward into Cascade, Republic and Holyoke formations. These divisions are placed in order as equivalent to the fundamental complex, lower Marquette series and upper Marquette series of Van Hise. They are unconformable and represent three different geological ages. The Keweenawan is divided into two divisions, both of which are placed in the Cambrian; the Lower Keweenawan, 25,000 ft. of interbedded conglomerates and lava flows, with some intrusives; Upper Keweenawan, 12,000 feet of sandstones and shales, not separable from the Potsdam or Eastern sandstone.

The Azoic or Archean system consists of rocks formed (1) by mechanical means, (2) by eruptive agencies, (3) by chemical action.

The Cascade, or oldest formation of sedimentary and eruptive rocks, consists, commencing with the oldest, of gneissoid granites or gneiss, basic eruptives and schists, jaspilites and associated iron ores, and granites, although the above arrangement may be considered no more than a hypothesis, and it is probable that the jaspilites and iron ores will be found to belong to the Republic formation. It is also probable that the Cascade formation itself will prove to be composed of two or more distinct geological formations, as shown by the fact that the chief rock of the Huron Mountains appears to be a gneissoid granite, rather than a true sedimentary gneiss. True sedimentary gneisses are found in the Huron Bay and Cascade districts. In the former area they contain fragments that closely resemble the gneissoid granites, and thus they appear to be formed from the debris of those rocks. If, however, the gneissoid granites are metamorphosed eruptive rocks, and not true gneisses (which are restricted to metamorphosed sedimentary rocks), this fact proves only that the gneisses are younger in order of time, but not of necessity of younger geological age. Similar statements apply to the breaks between the Cascade and Republic formations, and the break between the Republic and Holyoke formations. In the Huron Bay, Menominee and other districts the Cascade formation holds intrusive granites. Amphibole-schists are also found intrusive in the gneisses in the Cascade area. In the Marquette area the amphibole schists are cut by felsite or quartz-porphyry.

Much of the granite and felsite appear to have been erupted during the time of the Cascade formation, and perhaps even later. On the Cascade range hornblende-gneiss cuts the country rock. These dykes are cut by

[1] A Sketch of the Geology of the Iron, Gold and Copper Districts of Michigan, M. E. Wadsworth, Rep. State Board Geol. Sur., Michigan, 1891–2; pp. 75–174; Lansing, 1893. Also, see Annual Reports 1888–1892, ibid., pp. 38–73.

other dykes containing crystals of feldspar, while both are cut by gray granite, that is in turn cut by red granite.

The Republic formation, commencing with the oldest division, is divided roughly as follows: Conglomerate-breccia and conglomerate-schist; quartzite; dolomite; jaspilite and iron ore; argillite and schist; granite and felsite; diabase; diorite and porodite; porphyrite. At the base of the Republic formation is a series of conglomerates and conglomerate-schists, which pass into hydrous mica-schists. Near Palmer, the coarse conglomerate rests on the gneiss to the south, and is overlaid to the north by quartzite, fragmental jaspilite and quartz-schist. The dip is about 40° northward. The conglomerate contains numerous pebbles of gneiss, as well as some of granite, diorite, schist and quartz veins. Near the Volunteer mine quartzite immediately overlies the basal conglomerate, and in other places reposes directly on the Cascade formation.

The quartzite in the Menominee district, running from Sturgeon river along Pine river to Metropolitan, is thought to belong to the base of the Republic formation, since it is found at various places close to the gneiss and granite, dipping away from them, and is cut by dykes of granite in Sec. 12, T. 41 N., R. 30 W. The dolomite occupies a low horizon, either interbedded with the quartzite or occupying its place. The fundamental ore and jaspilite appears to belong, stratigraphically, to the Republic formation. The most of the jaspilite of the formation is of detrital origin, being originally conglomerates, breccias, sands, muds, which have been subsequently chemically acted upon by percolating waters, since in the Cascade range the jaspilite and ore form layers which are frequently interlaminated with quartzite. The jaspilite of Negaunee and Ishpeming has failed to reveal any evidence that it is sedimentary, although the associated argillite and schist are in part at least clearly sedimentary. The argillite and schists are directly associated with the jaspilite and iron ore. In places they grade up into the fragmental jaspilite, and in other places are interbedded with it. They also succeed the latter rocks and overlie them. These argillites and schists are older than the diorites of the district, and are cut by them.

The Holyoke formation has the following succession, as far as known, commencing with the base: Conglomerate breccia and conglomerate schist; quartzite; dolomite; argillite; graywacke and schist; granite and felsite; diabase, diorite and porodite; peridotite, serpentine and dolomite; melaphyr or picrite; diabase and melaphyr. The conglomerate at the base of the Holyoke contains granitic material, as well as fragments from the jaspilite. In many places the unconformity between the Republic and Holyoke formations is most marked, being seen at many of the mines. In many places, also, the Holyoke formation overlaps the Republic, and is in contact with the granite and gneiss of the Cascade. Associated with the Holyoke conglom-

erate is a quartzite which includes the Mt. Mesnard and Teal Lake quartzites. In Sec. 20, T. 47 N., R. 26 W., and Secs. 8 and 19, T. 49 N., R. 28 W., near Silver Lake and in other places, sediments of the Holyoke formation have sifted down into the fissures and joints of the preëxisting rocks, when they have a dyke-like character. For such formations the term "clasolite" is proposed. The dolomite of Mt. Mesnard and thence to Goose Lake, while lithologically, like that placed in the Republic formation, is doubtfully referred to the Holyoke. Argillite, graywacke and mica-schist occur extensively in the Holyoke, constituting the upper horizon. It is doubtful whether any granite or felsite of Holyoke age exists in the Marquette district.

Diabase, diorite, porodite, and peridotite occur abundantly, belonging both to the Republic and Holyoke formations. According to Mr. Seaman, diabase dykes of the Gogebic area are probably the same as those that cut the overlying sandstones of the Keweenawan, from which it is concluded that the Keweenawan lava flows are the effusive equivalents of the Holyoke diabase dykes.

The soft hematites of the region are produced by secondary enrichment at places where the water could best act, being at points of fracturing or in basins. The silica of the lean material has been leached out, and in its place iron oxide substituted. Gold and silver veins are discussed, and a classification of ore deposits given.

The Eastern or Potsdam sandstone rests unconformably on the Azoic. This includes the unaltered horizontal sandstone, which is free from dykes of eruptive material, and the Keweenawan, which consists of lava flows alternating with sandstones and conglomerates, largely derived from the former. Above, and conformably with the Eastern sandstone, near L'Anse, is limestone of Silurian age, as shown by its fossil contents. On Keweenaw Point the Eastern sandstone dips toward, and passes under, the interstratified sandstones and lavas of the Keweenawan. At or near the contact is a fault. However, at Douglas, Houghton and Hungarian rivers, it is thought not to be at the contact, and consequently that the Eastern sandstone underlies the Keweenawan lava, but the Eastern sandstone may contain two or more sandstones of different ages, which may perhaps be considered as the most probable explanation of all the evidence. In Sec. 13, T. 46 N., R. 41 W., on the South Trap range, a nearly horizontal, soft, friable micaceous sandstone is found near the interbedded Keweenawan melaphyr and indurated sandstone. This soft sandstone contains numerous spherical spots very common in the Eastern sandstone, but not found in the Keweenawan. In the soft sandstone are found pebbles and large angular fragments of indurated sandstone, which Mr. Seaman thinks could only have been derived from the adjacent indurated sandstone. The rocks of the Trap range here exposed are believed by Mr. Seaman to hold a position near the top of the Keweenawan series, and he

concluded that the soft sandstone belongs to a distinct and later geological age than the Trap range.

The character and origin of the copper deposits are discussed.

Comments.—The major structural conclusions independently reached by the Michigan Geological Survey are nearly identical with those which have been published by the officers of the United States Geological Survey. The same may be said as to the origin of the iron ores. Upon a few points there is, however, a difference of opinion.

The unconformity which exists between the Lower Marquette and the Basement Complex marks a distinct geological age, whether gneissoid granites composing the latter are metamorphosed eruptives or metamorphosed sedimentary rocks. It is true that a sedimentary formation resting upon an eruptive, and deriving material from it, is no evidence of a geological break if the eruptive is a surface rock and has not been altered before the overlying formation was deposited. If, however, the eruptive is a deep-seated rock, or has been so sheared and folded as to take on a schistose structure before the deposition of the succeeding formation, and has consequently reached the surface by erosion, the discordance may mark as great a geological break as an unconformity between a metamorphosed sedimentary rock and an unaltered overlying series.

That there is more than one geological period represented in the Cascade formation seems unlikely, and in a later note by Dr. Wadsworth this idea is apparently abandoned. If any gneisses of the Huron Mountain prove to be unconformably upon, and to have derived material from, an older gneissoid granite series, it is probable that this new series will be found to be equivalent to the Lower Marquette or Upper Marquette series rather than to belong to the Cascade formation.

Jaspillite and ore are tentatively placed as one of the kinds belonging to the Cascade formation or Basement Complex, although the major portion of them are placed in the higher series. No large areas of this rock yet discovered would be here placed by the reviewer. The jaspillite of Ishpeming and Negaunee doubtfully referred to the Cascade is believed to be a sedimentary deposit of the same age as similar rocks of the Lower Marquette series.

That the jasper near the base of the iron-bearing formation at Cascade is interlaminated with layers of fragmental material is not sufficient evidence that the jasper is or has been derived from a mechanical sediment. The inferior formation of the lower Huronian is usually, if not always, a clastic deposit, resting as it does unconformably upon an earlier series of granites, gneisses and schists. This fragmental formation usually grades up into the non-fragmental formation of the iron-bearing member, and before continuous pure non-clastic sediments are reached there are often several alternations of the two kinds of deposits. Such occurrences are exactly analogous to the

interlaminations of limestone with shale or sandstone at the transition horizon which frequently occurs when a limestone formation rests upon a sandstone formation.

As to the age of the Keweenawan, this series is placed by Dr. Wadsworth as a lower part of the Potsdam, but is regarded by the reviewer as resting unconformably below the Potsdam, and as belonging to a different geological period. This question is one of great complexity, which can not here be discussed in detail. However, Dr. Wadsworth refers the Keweenawan so doubtfully to the Potsdam that the difference can hardly be said to be a serious one. The statement that the most probable explanation of all the phenomena at Keweenaw Point is that the Eastern sandstone is of different ages can have but one meaning—that a part of this so-called Eastern sandstone belongs to the Potsdam, and this Potsdam is later than, and unconformably upon, the Keweenaw series, which latter includes another part of the Eastern sandstone. Put in another way, Dr. Wadsworth extends the term Eastern sandstone to cover all of the sandstone exposed until the Traps are reached. That is, the break between the Potsdam and Keweenawan is in places a short distance away from the Traps. This admits the difference in geological age between the main area of Potsdam sandstone and the Keweenawan, and merely shifts the boundary line between the two a short distance. It is notable that the most important new evidence presented upon the question is that obtained by Mr. Seaman, Dr. Wadsworth's assistant. Near the South Range he finds outcrops which he regards as Eastern sandstone, holding indurated fragments derived from adjacent ledges of upper Keweenawan sandstones, and hence believes the Eastern sandstone to represent a later geological age.

It appears to the writer very doubtful whether the large number of members given for the Republic and Holyoke series will be found to be general for the Lower Huronian and Upper Huronian on the south shore of Lake Sueprior, although each may be found at some locality.

Wadsworth[1] states that recent work renders it probable that the Azoic or Archean of Northern Michigan is divisible into five unconformable formations. The tentative arrangement, commencing with the oldest, with the parallel formations, as determined by the United States Geological Survey, is as follows:

MICHIGAN GEOL. SURVEY.	U. S. GEOL. SURVEY.
Cascade Formation.	Fundamental Complex.
Republic Formation Mesnard Formation	Lower Marquette series.
Holyoke Formation Negaunee Formation	Upper Marquette series.

[1] Subdivisions of the Azoic or Archean in Northern Michigan," by M. E. Wadsworth. In Am. Jour. of Sci., vol. xlv., No. 265, Jan., 1893, pp. 72, 73.

Comments.—The suggestion of the two additional unconformities in the Huronian of the Marquette district is so tentative that no criticism of it is necessary. The suggestion implies that Dr. Wadsworth thinks this outcome the most probable one. It appears to the writer, however, that it is far more probable that the true explanation is that there are only three unconformable pre-Keweenawan series. The additional unconformities are probably suggested by the considerable local variation in the character of both the Lower Huronian and Upper Huronian series, so that in different parts of the district the same series has very different aspects.

Lane[1] holds that certain of the ore bodies of the Marquette district are produced by abstracting iron oxide from amphibolites and depositing this material at other places. The water is regarded as upward moving, hence the ore bodies rest upon the diorites as foot walls. It is not denied that in other places the iron is derived from a carbonate, or that silicia is replaced by the iron oxide. At the Volunteer mine the ore seems in part to have replaced the sandstone.

Bell reports on the Sudbury mining district:[2] The rocks are divided into three groups, in ascending order: (1) A gneiss and hornblende-granite series — Laurentian. (2) A series comprising quartzites, massive graywackes, often holding rounded and angular fragments; slaty graywackes, with and without included fragments; drab and dark-gray argillites and clay-slates; dioritic, hornblendic, sericitic, felsitic, micaceous and other schists; and occasionally dolomites, together with large included masses or areas of pyriferous greenstones. This group constitutes the ordinary Huronian of the district. (3) A division consisting of a thick band of dark-colored silicious volcanic breccia and black slate (generally coarse), overlaid by drab and dark-gray argillaceous and nearly black, gritty sandstones and shaly bands. The breccia is underlaid in places by quartzite conglomerate. (4) In addition to these, dikes of diabase and gabbro cut through all the foregoing, and are, therefore, newer than any of them, although they may not belong to a later geological period.

Flanking the Huronian rocks on the southeast is gneiss, and on the northwest a mixture of gneiss and hornblende-granite. The first of these rocks is of the characteristic Laurentian type, but the hornblende-granite and quartz-syenite on the northwest are not always characteristic of the Laurentian. These rocks, however, pass into the gneiss in such a way, and are mingled with

[1] Microscopic characters of Rocks and Minerals." A. C. Lane. Rep. State Board Geol. Sur., Mich., for 1891-2, Lansing, 1892, pp. 176-183.

[2] Report on the Sudbury Mining District, by Robert Bell. Annual Rep. Geol. & Nat. Hist. Sur. of Canada for 1889–90. Vol. v, Part F, p. 95, with a geological map.

them both on a large and small scale, that it was impossible to separate them. Within the Huronian trough, and parallel with it, is also a tongue of gneiss and hornblende-granite two or three miles wide and thirty-nine miles long.

The Huronian division forms a part of the great Huronian belt, extending from Lake Superior and Lake Huron nearly to Lake Mittassini. The bedding of the Huronian is usually nearly vertical, or stands at high angles. Occasionally the rocks have been sheared by pressure. Graywacke-conglomerate, in places full of rounded pebbles of gray quartz-syenite, is found on the Blue River branch of the Spanish River, Lot 2, Con. III. In the township of Hyman is an Augen-gneiss which is evidently a metamorphosed clastic, as it forms a part of the quartzite and graywacke series. The line of junction between the Laurentian and Huronian is unusually straight. West of Lake Wahnapitae, along the contact, there is evidence of great disturbance and crushing, the rocks of the two series being much broken up and intermixed. It is not improbable that at the junction line is a considerable fault.

The third division is less altered, and is in a distinct basin running from the township of Trill northeastward to near the South Bay of Lake Wahnapitae, a distance of 36 miles, with a breadth of 8 miles in its central portion. These rocks are perhaps unconformable to the older Huronian rocks on which they rest, and may be Upper Huronian, or possibly lower Cambrian.

Along Onaping Lake and River, and along Straight Lake, are Huronian outliers. The principal kinds of rocks in the first basin are slate conglomerates, with well-rounded pebbles and boulders, mostly of binary granite, quartz, quartzite and schists; and coarse arenaceous or graywacke conglomerate, together with some pale-pink quartzites and blueish and greenish-gray felsites, argillites and slates. The principal rocks of the second basin are graywacke-schists, quartzites, quartzite or graywacke-conglomerates, green schists, hard sandstones, greenstones, and some dolomites. In the conglomerates are pebbles of graywacke and hornblende-granites like the prevailing varieties found in situ in the region, black slates and black and white quartz. On Lot 4, Con. III, Moncrieff, is the junction of the Laurentian red hornblende-granite and the graywacke.

It is concluded that the Huronian rocks of the Sudbury district are largely of volcanic nature, although many of them have been rearranged by water; hence they may be termed pyroclastic. The graywackes consist of granite debris more or less comminuted by the modifying action of water. Under this name is included many varieties of rocks, ranging from those which approach quartzites to others approaching argillites. The largest fragments are usually of red or gray aplite. As a general rule, the different divisions of the Huronian rocks do not maintain their thickness very far on the strike, but diminish more or less rapidly, their place at the same time being filled by a corresponding thickening of other members of the series.

The trappean rocks of the district consist of (1) extensive masses, together with many of smaller size, incorporated with the other Huronian rocks, and probably contemporaneous with them; and (2) dikes which cut through all the members of the series. There are nearly fifty areas of diorite, two principal belts of diabase, and a belt of slaty, greenish diorite, which in places becomes brecciated, and includes fragments, from large boulders down to small pebbles, consisting principally of quartzites, granites, and syenites.

Very numerous details are given, which cannot be summarized.

Comments.— The conclusion of Bell, that the Huronian is divisible into two divisions which are probably unconformable, corresponds with the more recent conclusions of those who have studied the Huronian of the Lake Superior region and the original Huronian of the north shore of Lake Huron. The area reported upon being a continuation of the Lake Huron Huronian, it is not surprising to find the dual character of this series continue.

No light is given upon the character of the floor upon which the earliest sedimentary rocks must have been deposited. That at several places are found water-deposited conglomerate which bear well-worn pebbles and boulders of granite, syenite, etc., which in one case are said to be exactly like the granite found in situ, seems conclusive evidence that granite and syenite existed in the region in a consolidated condition before the Huronian members containing this detritus were laid down. A part of these conglomerates clearly belong to Bell's older division of the Huronian, but this series is not divided into formations, consequently we have no information as to whether or not these conglomerates are at the bottom of the series.

Williams, [2] gives microscopical notes on various rocks from the Sudbury district. The sedimentary rocks are found to include those which are plainly clastic, those which are clastic but partially re-crystallized, and those which are highly crystalline, but probably derived from clastics. In the last division are placed felsite, gneiss-conglomerate, and gneiss. The eruptives, including various acid and basic deep-seated and surface rocks, also show extensive metamorphism and re-crystallization. Placed among the highly crystalline rock, probably derived from the clastics, are certain felsites, gneiss-conglomerates, and gneisses. Certain granites, gneisses and schists are of uncertain origin, but give no indication of clastic derivation.

C. R. VAN HISE.

[2] "Notes on the Microscopical Character of Rocks from the Sudbury Mining District, Canada," by George H. Williams. Annual Rep. Geol. & Nat. Hist. Sur. of Canada for 1889–90, vol. V, Part F, Appendix I, pp. 55–82.

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THEORIES OF THE ORIGIN OF MOUNTAIN RANGES.

Mountains are the focal points of geological interest. In their complex structure are contained all kinds of rocks, sedimentary, eruptive and metamorphic; and in their formation are engaged all geological forces in their greatest intensity. They are the culminating points, the theatres of greatest activity of all geological agencies; igneous agencies in their formation, aqueous agencies by sedimentation in their preparation, and by erosion in their subsequent sculpture. Their discussion, therefore, is a summation of all the principles of structural and dynamical geology. But they are equally important in historical geology, for the birth of mountains marks the times of great revolutions in the history of the earth, and therefore determine the primary divisions of geological time. Evidently therefore the theory of mountains lies at the very basis of theoretic geology, and a true theory must throw abundant light on many of the most difficult problems of our science.

But if this is the most important, it is also the most difficult of all geological questions. My object now is to give, as briefly as possible, the present condition of science on this subject. But in all complex subjects there is a region of comparative certainty and a region of uncertainty; a region of light and a region of twilight. My farther object, therefore, will be to separate sharply these two regions from one another, and thus to clear the ground, narrow the field of discussion and direct the course of profitable investigation.

But first of all I must define my subject. A mountain range is a single *mountain individual*—born at one time (monogenetic) *i.e.*, the result of one—though it may be a prolonged—earth-effort; as contra-distinguished on the one hand from a mountain *system* which is a family of mountain ranges born at different times (polygenetic) in the same general region; and on the other from ridges and peaks which are subordinate parts—limbs and organs—of such a mountain individual. Now a theory of mountains is essentially a theory of mountain ranges, as thus defined. In all that follows, therefore, on the subject of mountain structure and origin, we refer to mountain ranges.

STRUCTURE OF MOUNTAINS.

The origin of mountains is revealed in their structure. We must, therefore, give briefly those fundamental points of structure on which every true theory of origin must be founded.

1. *Thickness of Mountain Sediments.*—The enormous thickness of mountain strata is well known, but it is impossible to overstate its fundamental importance. We therefore give some striking examples. The Palæozoic rocks involved in the folded structure of the Appalachian, according to Hall, are about 40,000 feet thick. The Palæozoics and the Mesozoics in the Wasatch, according to King, are about 50,000 feet thick. The Cretaceous alone, in the Coast Range of California near the Bay of San Francisco, according to Whitney, are 20,000, and in Shasta county, according to Diller, are 30,000 feet thick. The Mesozoics and Tertiaries of the Alps, according to Alpine geologists, are 50,000 feet.[1] The upper Palæozoic and Mesozoic of the Uinta, according to Powell, are 30,000 feet. These are conspicuous examples, but the same is true of all mountains.

It might be objected that these numbers express the general thickness of the stratified crust everywhere—only that in mountains the strata are turned up and their thickness exposed by erosion. But this is not true. For in many cases the strata may be traced away from the mountain; and in such cases they always *thin out* as distance increases. For example, the 40,000 feet of

[1] JUDD: Volcanoes, p. 295.

Appalachian Palæozoics thin out going west until at the Mississippi river they are only 2000 to 4000 feet. The Palæozoics which in the Wasatch are 30,000 feet thin out eastward until they are only 1000 feet on the plains. It follows then that *mountains are lines of exceptionally thick sediments.*

2. *Coarseness of Mountain Sediments.*—Mountains are composed mainly of grits, sandstones, and shales, *i.e.*, of mechanical sediments, and most conspicuously so along their axial regions. As we go from this region, sometimes in either direction, but especially in one direction, the strata become finer and finer; sandstones giving way to shales and shales to limestones, *i.e.*, mechanical to organic sediments. This is conspicuously true of the Appalachian; in so many ways a typical mountain. As we pass from the eastern ridge westward, grits and sandstones are replaced by shales and these by limestones. Therefore mountains are also *lines of exceptionally coarse sediments.*

3. *Folded Structure of Mountains.*—The folded structure of mountains is perhaps the most universal, and certainly the most significant, of all their features. But there is great variety in the degree and complexity of the foldings. Sometimes the mountain rises as *one* great fold. The Uinta is an example of this. Sometimes and oftener there are *several open* folds, like waves of the sea. The Jura is a good example of this. Sometimes and oftenest of all, there are *many closely appressed* folds. This is the case in the Coast Range of California, in the Appalachian, in the Alps, and probably in the Sierra. The Appalachian may be taken again as the type. In this range the folds are most numerous and most closely appressed in the axial region, and open out and die away in gentle waves as we go westward. Finally, sometimes in extreme cases, as in the Alps, the Pyrenees and probably the Sierra, the strata of the lateral slopes are thrust in under the central and higher parts, so that the strata of these central parts are overfolded outwards on one or both sides. This is the *Fan-structure*, so marked in the Alps and Pyrenees, where the underthrust and overfold are on both sides, but found also in the Appalachian and Sierra, where they are on one side only.

Amount of Folding.—Folded structure implies, of course, an alternation of anticlines and synclines. The number of these varies with the intensity of the folding. In the Coast Range there are apparently four or five anticlines and corresponding synclines. In the Sierra they cannot be counted, but there must be very many so closely appressed that the strata seem to be a continuous series dipping all in the same direction, *i.e.*, steeply toward the axis, for at least 30 miles. They cannot form a single series, for this would make an incredible thickness. It must be a series repeated several times by extreme folding; how many, it is impossible now to say. In the Appalachian, according to Claypole[1], there are about 19 anticlines and synclines in 65 miles and in one part—Cumberland valley—there are eight in 16 miles. In the Vaudoise Alps, according to Renevier, there are at least seven[2], and in Savoy as many as 15[3]. In many cases the foldings are so extreme that the strata first rise as folds, then are pushed over beyond the base as overfolds, and finally broken at the crest and upper limb of the fold is pushed over the lower limb many miles horizontally. In the Highlands of Scotland, according to Peach[4], by overthrust, the Archæan is brought over the Silurian and overrides it for ten miles. In the Rocky Mountains of Canada, according to McConnell[5], the Cambrian is brought over the Cretaceous and overrides it for seven miles. In the Appalachian of Georgia, according to Hayes[6], by overthrust, the Cambrian is made to override the Carboniferous for eleven miles.

4. *Cleavage Structure.*—Closely connected with the last, and having a similar significance, viz., lateral squeezing and mashing, is another structure—*cleavage.* This structure is often asso-

[1] Am'n Nat'st, Vol. 19, p. 257 and seq.

[2] Archives des Science, Vol. 59, p. 5, 1877.

[3] Archives, Vol. 28, p. 608, 1892, and 25, p. 271, 1893.

[4] Nature, Vol. 31, p. 29, 1884.

[5] Geol. Surv. Can. 1886, Rep. D. p. 33.

[6] Bull. Geol. Soc. Am. Vol. 2, p. 141.

ciated with folding and both with mountain ranges. It is not so universal as folding only because all kinds of strata are not equally affected by it; being well exhibited only in fine shales. It is important to observe that in slaty cleavage the *strike* of the cleavage planes is the same as that of the strata, and both the same as the trend of the mountain; and that the *dip* of the cleavage planes is nearly or quite vertical. Whole mountains are thus cleavable from top to bottom.

5. *Granite or Metamorphic Axis.*—Some mountains are made up wholly of folded strata. This is the case with the Appalachian, the Coast Range, and the Jura. But most great mountains consist of a granitic or metamorphic axis with stratified flanks. This is conspicuously the case with the Sierra, the Alps, and most other great mountains. So general is this, that the typical structure of ranges may be said to be—a granitic axis forming the crest, and stratified rocks, more or less folded, outcropping on the slopes. This very characteristic structure ought to be explained by a true theory of origin.

6. *Asymmetric Form.*—Mountains are not usually symmetric, with crest in the middle and slopes equal on the two sides. On the contrary they usually have a long slope on one side and a steeper, often a very abrupt, slope on the other. The crest or axis is not in the middle but nearer to one side. The earth-wave seems ready to break and often does break with a great fault on the steeper side. The Uinta is perhaps the simplest example. This range rises as a single great fold, but steeper on the north side where there is a fracture and fault of 20,000 feet vertical. Of course in this as in all cases the original fault-cliff has crumbled down to a steep slope, or even been destroyed entirely. The Sierra and Wasatch are remarkable examples of asymmetry. The Sierra rises on the west side from the San Joaquin plains near sea level by a gentle slope fifty to sixty miles long, reaches its crest near 15,000 feet high and then plunges down by a slope so steep, that the desert plains on the east, 4,000 to 5,000 feet above sea level is reached in six to ten miles. There is on this side a fault-cliff nearly 11,000 feet high. The Wasatch

has a similar form, except that the fault-cliff looks westward instead of eastward. It is true that the extreme asymmetry of these two mountains was given them long after their origin and by a different process to be presently described. But even before this last movement they were probably asymmetric, though in a less degree. The Appalachian is perhaps here again a typical mountain. Its long slope is to the west and its crest close to the eastern limit. The Alps, the Appenines, the Carpathians, and the Caucasus, according to Suess, are foreign examples of the same form.

There are many other interesting points of structure that might be mentioned, but they are less significant of mode of origin and therefore omitted in this rapid sketch.

ANOTHER TYPE OF MOUNTAINS.

I have given the main characteristics of mountains of the usual type, of which the Appalachian, the Coast Range, the Alps and Pyrenees may be taken as good examples. But there is another type, different in structure and in mode of origin, to which attention, I believe, was first called by Gilbert. It is doubtful if they are found anywhere except in the Basin and Plateau regions, and therefore the type may be called the Basin region type. The Basin and Plateau regions are broken by north and south fissures into great crust-blocks which by gravitative readjustment have been tilted, *i. e.*, one side heaved up and the other side dropped down, so as to form a series of north and south ridges and valleys. Each ridge rises by a long slope on one side to a crest and then drops by a steep fault-cliff on the other. The ridges therefore are extremely asymmetric but the asymmetry is produced in a different way from that of the usual type. In a word, these mountains seem to be the result of a series of enormous parallel faults. Such faults are common everywhere, but do not usually give rise to any inequalities which may be dignified by the term mountain: or if so at one time, have since been levelled by erosion. But those in the Basin region are on so grand a scale and so recent in time, that they form

very conspicuous orographic features. I have sometimes doubted whether they should be called ranges at all; but when we reflect that at least 10,000 feet of the height of the Sierra is due to normal faulting, it seems impossible to withhold the term. Thus mountains may be divided into two types, viz., mountains formed by folding of strata and mountains formed by tilting of crust-blocks. The structure of the one is *anti*clinal or *di*clinal, of the other *mono*clinal. The Sierra probably belongs to both types. It was formed at the end of the Jurassic as a mountain of the first type, but the whole Sierra block was tilted up on its eastern side without folding, at the end of the Tertiary, and it then became also a mountain of the second type.

A complete theory must explain this type also; but since from its exceptional character it must be regarded as of subordinate importance, we shall be compelled to confine our discussion to mountains of the usual type.

EXPLANATION OF THE PRECEDING PHENOMENA.

In all cases of complex phenomena there have been many theories, becoming successively more and more comprehensive. The citadel of truth is not usually taken at once by storm, but only by very gradual approaches. First comes the collection of carefully observed facts. But bare facts are not science. They are only the raw material of science. Next comes the grouping of these facts by laws more or less general. This is the beginning of true science. Every such grouping or reducing to law is a scientific explanation, and therefore in some sense a theory. At first the grouping includes only a few facts. The explanation or theory lies so close to the facts as to be scarcely distinguishable from them. It is a mere corollary or necessary inference. It is modest, narrow, but also in the same proportion *certain.* Then the group of explained facts becomes wider and wider, the laws more and more general, and the theory more daring (but in the same proportion also perhaps more doubtful): until it may at last include the Cosmos itself in its boundless but shadowy embrace.

Now in this gradual approach toward perfect knowledge, there

are two very distinct stages. The one consists of explanation of the immediate phenomena in hand. This gives the laws of the phenomena, and may be called the *Formal Theory*. The other explains the cause of these laws, and may be called the *Causal or Physical Theory*. All science passes through these two stages. For example: Until Kepler, the phenomena of Planetary motion were a mere chaotic mass of observed facts without uniting law. Kepler reduced this chaos to order by the discovery of the three great laws which go by his name. This is the *formal* theory of Planetary motion. But still there remained the question, why do planets move according to these beautiful laws? Newton explained this by the law of gravitation. This is the causal or *physical* theory.

But this is so important a distinction that I must illustrate by examples taken from geological science. All the phenomena of slaty cleavage are completely explained by supposing the whole rocky mass to have been mashed together horizontally and extended vertically. This is the Formal theory and may be regarded as certain. But still the question remains: How does mashing produce easy splitting in certain directions? The solution of this question is the Physical theory, and is perhaps a little more doubtful, though I think satisfactorily answered by Tyndall. But still there remains a deeper and more doubtful question, Whence is derived the mashing force? Is it general interior contraction, as some think, or is it local expansion as others think. A perfect theory must answer all these questions. Take another example: All the phenomena of the drift are well explained by the former existence of an ice sheet moving southward by laws of glacial motion, scoring, polishing, and depositing in its course. This is the Formal theory. But still the question remains, What was the cause of the ice sheet? Was it due to northern elevation, or to Aphelian winter concurring with great eccentricity of the earth's orbit? And if due to northern elevation, what was the cause of that elevation? A perfect theory must answer all these questions. Take one more example: All the phenomena of earthquakes are completely explained by the emergence on the surface

and a spreading there from a centre, of a series of elastic earth-waves. This is the Formal theory. It explains the immediate facts observed here on the surface, but no more. But still remains the question, What is the *cause*, deep down below, of the concussion which determined the series of earth-waves. This, the physical theory, is far more doubtful. Or the theory may be made still deeper and proportionately more doubtful. If our theory of the cause of the interior concussion be the formation of a fissure or readjustment of a fault, as seems in many cases probable, there would still remain the question of the cause of great fissures and of their subsequent readjustment by slipping. This is probably as far as geological theory would go: for although cosmogony may go still farther, the interior heat of the earth is usually the final term of strictly geological theories.

I have made this long detour because I wish to keep clear in the mind these two stages of theorizing in the case of Mountain Origin. The formal theory is already well advanced toward a satisfactory condition; the physical theory is still in a very chaotic state. But these two kinds of theories have been often confounded with one another in the popular and even in the scientific mind and the chaotic state of the latter has been carried over and credited to the former also; so that many seem to think that the whole subject of mountain-origin is yet wholly in air and without any solid the foundation.

I. FORMAL THEORY.

A true formal theory, keeping close to the immediate facts in hand, must pass gradually from necessary inferences from smaller groups, to a wider theory which shall explain them all.

Inferences from 1 and 2, i. e., Thickness and Coarseness of Sediments.—The thickness of mountain sediments, as we have seen, is greatest along the axis and grows less as we pass away from that line. Now where do we find lines of very thick sediments forming at the present time? The answer is: On sea bottoms closely bordering continents. The whole washings of continents accumulate very abundantly along shore lines and thin out sea-

ward. Mountains were therefore born of sea-margin deposits. This view is entirely confirmed by the character of mountain sediments. We have seen that these are coarsest near the crest, becoming finer and then changing into limestones as we pass farther and farther away from the crest. Now this is exactly what we find in off-shore deposits. They are coarse sands and shingle near shore, and then become progressively finer seaward, until in open sea beyond the reach of even the finest mechanical sediments, they are replaced by organic sediments which form limestones. It seems evident, therefore, that the place of a mountain-range before mountain-birth was a marginal sea-bottom receiving abundant sediment from a contiguous continental land-mass. This explains at once the usual position of mountains on the borders of continents. Here, then, is one important point gained.

But such enormous thickness as we often find would be impossible unless the conditions of sedimentation on the same spot were continually renewed by *pari passu* subsidence of the sea-bottom. And we do indeed find abundant evidence of such *pari passu* subsidence, not only at the present time in places where abundant sediments are depositing, but also in the strata of all mountain ranges. In the 40,000 feet thickness of Appalachian strata nearly every stratum gives evidence by its fossils, of shallow water, and often by shore marks of all kinds, of *very* shallow water. Therefore the place of mountains while in preparation, in embryo, before birth, *was gradually subsiding, as if borne down by the weight of the accumulating sediments*, and continued thus to subside until the moment of birth, when of course a contrary movement commenced. The earth's crust on which the sediments accumulated was bent into a great trough, or what Dana calls a Geo-Syncline. This is another important poined gained.

But let us follow out our logic. If the earth's crust yields under increasing weight of accumulating sediments, then ought it also to rise under the decreasing weight of eroded land surfaces. If it sinks by loading it ought also to rise by unloading.

And such indeed seems to have been the fact. For if all the strata which have been removed from existing plateaus and mountains were restored, it would make an incredible height of land. At least 10,000 to 12,000 feet have been carried away by erosion from the Colorado Plateau region and yet 8,000 feet remain. At least 30,000 feet have been worn away from the Uinta Mountains and yet 10,000 feet remain. Evidently there has been a rise *pari passu* with the lightening by erosion.

May we not then safely generalize? May we not conclude with Dutton that the earth in its general form and in its greater inequalities is in a state of gravitative equilibrium—that the earth is oblate spheroid, only because this is the form of gravitative equilibrium of a rotating body; that ocean basins and continental protuberances exist, only because the materials underlying the former are denser, and underlying the latter lighter than the average. It is true that the spheroid form of the earth and the sinking and rising of the crust by loading and unloading may be explained on the supposition that the earth is liquid beneath a thin crust, but to this view there are three fatal objections. 1. The cosmic behavior of the earth is that of a rigid solid. This I believe to have been demonstrated. 2. The existence of the present great inequalities of the earth would be impossible, except under the most improbable conditions. For example, if the earth be fluid then the crust must rest as a floating body. But if so, then, by the laws of floatation, for every continental protuberance on the upper side there must be a corresponding protuberance in reverse on the other side of the crust, and for every great plateau or mountain range there must be a corresponding plateau or mountain range in reverse. And taking the difference of specific gravity of the floating crust and the supporting liquid to be as great as that between ice and water, these reverse inequalities must be ten times as great as those at surface! Can we accept so violent an hypothesis? But (3) repeated experiments, especially very recent ones by Carl Barus,[1] prove that rocks

[1] Am. Journal, vol. 45, p. 1., 1893.

increase very notably in density in the act of solidification, so that a solid crust would undoubtedly break up and sink in a liquid of the same material. But how then are we to explain gravitative equilibrium in the case of a rigidly solid globe. I answer, by two suppositions. 1. That the earth, though rigid as glass or even steel, to *rapidly* acting force, yet yields *viscously* to heavy pressuse *over large areas* and acting *for a long time*. A solid globe of glass six feet in diameter will very perceptibly change form under its own weight. How much more the earth under its own gravity. This completely explains the oblateness of the earth even if solid throughout and had never been liquid at all. The earth, though rigid, behaves like a very stiffly viscous body; like, for example, the ice of glaciers though very much more stiffly viscous. This viscosity would not at all interfere with its rigidity under the tide-generating influences of the sun and moon — for these are far too rapidly acting.

2. The second supposition necessary is, that the earth is *not* absolutely *homogeneous* either in density, or in conductivity for heat, that in secular cooling and contraction the denser and more conductive areas, cooling and contracting faster, went down and became the ocean basins, while the lighter and less conductive areas were left as the more prominent land surfaces. And thus to-day the ocean basins are in gravitative equilibrium with the continental areas, because in proportion as oceanic radii are shorter are the materials also *denser;* and in proportion as the continental radii are *longer*, are the materials also specifically *lighter*. This condition of gravitative equilibrium Dutton calls *Isostasy*.

Thus then the great inequalities of the earth, constituting ocean basins and continental surfaces, are the result of *unequal radial descent of the earth's surface* by contraction in its secular cooling. This is by far the most satisfactory theory of these *greatest* inequalities.

In thus following the phenomena of Isostasy to their logical conclusion, we seem to have gone beyond the limits of our subject, which is the *theory of mountains:* but the close connection which probably exists between the cause of continents and the

cause of mountains justifies the digression, if such it may be called.

Inferences from 3 and 4, Folding and Cleavage.—Still adhering closely to observed facts, there are some necessary inferences from folded structure and cleavage. These structures are indisputable proofs that mountain strata have been subjected to enormous *lateral* pressure at right angles to the trend of the axis, by which the whole mass has been mashed together horizontally. But such horizontal mashing must of necessity produce corresponding up-swelling along the line of yielding. In a word, it is evident that mountains have been uplifted largely, at least, if not wholly, by horizontal mashing. The only question that remains is, Is lateral mashing alone sufficient to produce the highest mountains? Let us see.

The amount of uplift in such cases would depend on two things, viz., the thickness of the strata and the amount of mashing. Now, as already shown, mountain sediments are 30,000, 40,000 and even 50,000 feet thick. The amount of mashing in many mountains is almost incredible. In the Appalachian it is so extreme that in one place, according to Claypole, ninety-six miles of the original sediments have been crowded into sixteen miles, and the shortening of the whole Appalachian breadth is estimated as eighty-eight miles.[1] In the Alps the shortening is estimated by Heim at seventy-two miles or one-half the original breadth of the sediments.[2] In a word, we may without exaggeration say that, in great mountains, the original space is to the folded space as two to one, or even three to one. Now a crushing of 30,000 feet of sediments into one-half their original space would double their thickness, which is equivalent to a clear elevation of 30,000 feet. But strata are 40,000 and even 50,000 feet thick. Evidently then this method alone is sufficient to account for the highest mountains in the world, even allowing for the enormous erosion which they have suffered.

The same is equally shown by the phenomena of slaty cleav-

[1] Amn. Natst. Vol. 19, p. 257.

[2] HEIM: Archives des Sciences, Vol. 64, p. 120, 1878.

age so often associated with folded structure. Slaty cleavage, as has been demonstrated by experiment, as well as by field observation, is produced by a mashing together of the whole rocky mass in a direction at right angles to the cleavage plane and a corresponding extension in the direction of the *dip* of these planes. Now since the cleavage dip is usually nearly or quite vertical, this means a mashing together *horizontally* and a proportionate extension *vertically*. The amount of mashing together horizontally and extension vertically has been in many cases somewhat accurately estimated. In this case also, as in folding, we have evidence of a mashing of two or even three into one and a corresponding extension vertically of one into two or even three. This amount of extension affecting thick strata is sufficient to account for the highest mountains in the world without resorting to any hypothetical force pushing upward from beneath.

There seems therefore to be no reasonable doubt that *mountains are formed wholly by lateral crushing with proportionate upswelling*. This is a very important point gained. Let us hold it fast. This brings me naturally to the next point.

Inferences from 5 and 6, Granitic Axis and Asymmetric Form.—A granitic or metamorphic axis is a very general, though not a universal, characteristic of mountains. The old idea (still held by some) was that fused matter was pushed up through and appeared above, the parted strata along the crest as the granite axis, lifting the strata, as it were, on its shoulders to form the slopes. But it must be observed that the axis is often only metamorphic, not granitic, and moreover that some mountains are composed wholly of folded strata alone. If, therefore, we regard granite as often only the last term of metamorphism, we may more properly speak of the axis of mountains as metamorphic. If so, then it is not necessary to suppose any vertical uprising of fused matter by volcanic forces at all. On the contrary, we would explain the axis thus :

It is evident that accumulating sediments must cause corresponding rise of the interior heat of earth toward the surface so as to invade the lower parts of the sediments and their included

water. Now it is well known from the experiments of Daubreé and others, that in the presence of water, even in small quantities, rocks become softened and even hydrothermally fused at the very moderate temperature of 400° to 800° F. It is certain then that such thickness of sediments as we know accumulated in preparation for mountain birth, must have been softened to a degree proportionate to the thickness, and therefore perhaps semifused or even fused in their lower parts along the line of *thickest* deposit, and therefore of greatest subsequent elevation. On cooling after elevation, this sub-mountain fused or semifused matter would form a granitic or metamorphic *core* beneath the highest part. The appearance of this core as an axis along the crest is the result not of up-thrust but of *subsequent erosion* greatest along this line.

And this, in its turn, furnishes a key to the location of mountains along lines of thick sediments. For not only the lower parts of such sediments but also the sea-floor on which they are laid down would be hydrothermally softened or even fused. Thus would be determined a line of *weakness*, and therefore a line of yielding to lateral thrust, and therefore also a line of crushing, folding, and upheaval. The folding and the upswelling and the metamorphism would be greatest along the line of thickest sediments and become less as we pass away from that line. In extreme cases, however, the firmer lateral portions might be jammed in under the softer central portions, on one or both sides, and give rise to the Fan-structure character of complexly folded mountains. Or again, in such cases the folds might be pushed clean over and broken at the bend, and then the upper limb slidden over the lower limb even for miles, forming the wonderful thrust-planes of the Alps, the Appalachian and the Rocky Mountains, already described. Thus the phenomena under (5) is completely explained.

But mountains are usually asymmetric, the crest being on one side. This is explained as follows: Sedimentary accumulations along shore lines are thickest *near* shore (though not *at* shore) and thin out slowly seaward. The cilinder-lens formed by sedimentation is not symmetric, its thickest part being near one side, and

that the shore side. This thickest line, as we have seen, becomes the crest, which therefore is asymmetrically placed on the land-side or side from which the sediments were derived. The over-folding on the contrary is to the sea-ward.

SUMMARY STATEMENT OF THE FORMAL THEORY.

We may therefore group all these inferences and sum up our view of the mode of mountain formation thus:

1. Mountain ranges, while in preparation for future birth, were marginal sea-bottoms receiving abundant sediment from an adjacent land-mass and slowly subsiding under the increasing weight. 2. They were at first formed, and continued for a time to grow, by *lateral pressure* crushing and folding the strata together horizontally and swelling them up vertically along a certain line of easiest yielding. 3. That this line of easiest yielding is determined by the hydrothermal softening of the earth's crust along the line of thickest sedimentation. 4. That this line, by softening, becomes also the line of greatest metamorphism; and by yielding, the line of greatest folding and greatest elevation. But (5) when the softening is very great sometimes the harder lateral strata are jammed in under the crest, giving rise to Fan-structure, in which case the most complex foldings may be near but not at the crest. Finally (6) the mountains thus formed will be asymmetric because the sedimentary cilinder-lenses from which they originated were asymmetric.

SOME EXAMPLES ILLUSTRATING.

It is hardly necessary to enforce these views by illustrative examples. They at once arise in the mind of every geologist. But there are those in this audience who are not geologists. I therefore select a few examples among our own mountains.

1. *Appalachian*. It is well known that during the whole Palæozoic, the region now occupied by the Appalachian was the eastern marginal bottom of the great interior Palæozoic Sea, receiving abundant sediments from an eastern land mass of Archæan rocks, which then extended far beyond the present limits of the continent and whose western coast-line was a little to the east

of the present Appalachian crest. The sediments along this marginal sea-bottom increased in thickness during Cambrian, Silurian, Devonian and Carboniferous (with some changes of Physical Geography, but without greatly changing the line of sedimentation) until 40,000 feet thickness was reached. Such thickness, of course, could not be attained without *pari passu* subsidence. We have additional evidence of this in shallow water fossils and even shore marks at many levels in the series. At the end of the coal period, when 40,000 feet had accumulated, the increasing softening along the line caused it finally to yield to horizontal thrust; the whole mass of strata was crumpled together and swelled up along the line of sedimentation and the Appalachian Range was born. The same forces which caused its birth continued to cause its *growth* for a long time. Subsequent erosion has sculptured it into its present form, but *has not exposed its granite core*. The crest is on the east or landward side, as we should expect, and the overfolds are to the west or toward the sea of that time. This is perhaps the most typical example we have.

2. *Sierra.*—If it were not for a subsequent movement so late as the beginning of the Quaternary, which greatly modified its form, the Sierra too would be a typical range. During the whole Palæozoic and the greater part of the Mesozoic the place now occupied by the Sierra was the eastern marginal bottom of the Pacific, receiving sediments from a continental land-mass in the present Basin region. The shore line changed somewhat at the end of the Palæozoic, but the Sierra region maintained a sea bottom position. At the end of the Jura, when an enormous thickness had accumulated, the increasing softening of the crust determined a yielding to lateral thrust and consequent formation of the range. Subsequent erosion has completely removed the strata from the crest and exposed the granitic core as an axis[1]. This axis is here also on the landward side, and the overfolds are

[1] Sierra granite is not Archæan as has been asserted by some, nor does it all antedate the birth of the range. This is proved (1) by the gradation traceable between slates and granites, and (2) by the fact stated by Whitney, by Fairbanks, and by Diller—that the granite in many places penetrates the slate as veins.

to the seaward as in the Appalachian. The erosion of the Cretaceous and Tertiary times probably cut down the Sierra to very moderate proportions and reduced it to an almost senile condition. At the end of the Tertiary a great fault and bodily uplift of the whole Sierra block on its east side transferred its crest to the extreme eastern margin, greatly increasing its height and rejuvenating its erosive vigor.

3. *Coast Range.*—The formation of the Sierra transferred the coast line westward of that range and the present place of Coast Range became marginal sea-bottom, receiving sediment from a now greatly increased land-mass. This continued until the end of the Miocene when the Coast Range was similarly formed.

We might multiply examples, but these are deemed sufficient to illustrate the principles.

MINOR PHENOMENA.

We have given only the most fundamental phenomena, *i.e.*, those which reveal the mode of origin, and upon which, therefore, a true theory must be founded. But all other minor phenomena associated with mountains are well explained by the view above presented and their explanation confirms the view. For example:

1. *Eruptive Phenomena.*—We have seen that beneath a mountain, before and at the time of its formation, there is a deep-seated core of liquid or semiliquid matter. Also it is evident that the strong foldings of the strata in the act of mountain formation must produce fissures parallel to the folds and to the mountain axis, and that these fissures may reach down to the submountain liquid matter. In the act of mountain formation, therefore, the submountain liquid must be squeezed into the fissures forming dikes, or through the fissures and poured out on the surface as great lava floods, covering sometimes thousands of square miles. In most cases subsequent erosion has swept these overflows clean away leaving only their roots as intersecting dikes. Only the most recent still remain. On these great fissure-eruption lava-fields, ordinary volcanic or crater eruptions continue for ages

after the mountain formation ceases. In these, however, materials are ejected not by mountain-making forces, but by the elastic force of vapor from percolating waters. All these eruptive phenomena are, therefore, associated with mountain ranges.

2. *Faults.*—In folding, and especially overfolding, the strata are, of course, often broken and the upper wall of the fissure is pushed over the lower wall by horizontal thrust often thousands of feet, forming reverse faults and so-called thrust planes. Hence this style of faults are everywhere associated with strongly folded rocks, and, therefore, with mountains, and are indisputable evidence of horizontal crushing. In other places than mountains, and in horizontal or gently folded rocks, the other style of faults, *i. e.*, normal faults, are more common.

3. *Mineral Veins.*—The filling of fissures at the moment of formation with fused matter constitute dikes; but if not so filled, they are afterwards filled by a slow process of deposit from circulating waters and then they form mineral veins. These, therefore, are also common in mountains.

4. *Earthquakes.*—Again, the immense dislocations of strata which we find in faults did not occur all at once, but slowly through great lapse of time; and yet on the other hand not by uniform slipping, but by jerks, a little at a time. Every such readjustment of the walls of a fissure, whether by increasing lateral pressure (reverse faults) or by gravity (normal faults), gives rise to an earthquake. Earthquakes, therefore, although not confined to, are most common in mountain regions, especially if the mountains are still growing.

Thus, leaving out the monoclinal type which seems to belong to different category, all the phenomena, major and minor, of structure and of occurrences connected with mountains, are well explained by the theory of *lateral pressure* acting on lines of thick sediments accumulated on marginal sea-bottoms and softened by invasion of interior heat. This view is therefore satisfactory as far as it goes, and brings order out of the chaos of mountain phenomena. It has successfully directed geological investigation in the past and will continue to do so in the future.

But there still remains the question: "*What is the cause of the lateral pressure?*" The answer to this question constitutes the *physical theory.*

Thus far I suppose there is little difference of opinion. I have only tried to put in clear condensed form what most geologists hold. But henceforward there are the most widely diverse views and even the wildest speculations. But let us not imagine, on that account that we have made no progress in the science of mountain-origin. The *formal theory* already given is really for the geologist by far the most important part of the theory of mountain-origin. For I insist that for the geologist *formal* theories are usually more important than *physical* theories of geological phenomena. That slaty cleavage is the result of a mashing of strata by a force at right angles to the cleavage-planes, is of capital importance to the geologist, for it is a guide to all his investigations. To what property of matter this structure is due is of less importance to him, though of prime importance to the physicist. That the phenomena of the drift is due to the former existence of a moving ice-sheet is the one thing most important to the geologist, guiding all his investigations. Whether this ice-sheet was caused by geographical or astronomical changes is a question of wider but of less direct interest to him. So in the case of mountain ranges, the most important part of the theory is their origin by lateral pressure under the conditions given above. The *cause* of the lateral pressure, though still of extreme interest, is certainly of less immediate importance in guiding investigations.

PHYSICAL THEORIES.

The most obvious view of the cause of lateral pressure refers it to the *interior contraction of the earth.* This may be called the

"CONTRACTIONAL THEORY."

This theory is so well known that I will give it only in very brief outline. It assumes that the earth was once an incandescent liquid and has cooled and solidified to its present condition. At first it cooled most rapidly at the surface and must have fissured

by tension. But there would inevitably come a time when the surface being substantially cool and moreover receiving heat also from the sun, its temperature would be fixed or nearly so, while the incandescent interior would be still cooling and contracting. Such has probably been the case ever since the commencement of the *recorded* history of the earth. The hot interior now cooling and contracting more rapidly than the cool crust, the latter following down the ever shrinking nucleus would be thrust upon itself by lateral pressure with a force which is simply irresistible. If the crust were ten times, yea one hundred times more rigid than it is, it must yield. It does yield along the lines of greatest weakness, *i. e.*, along marginal sea-bottoms as already explained. As a first attempt at a physical theory, it seems reasonable, and therefore, until recently, has been generally accepted.

OBJECTIONS TO THE CONTRACTIONAL THEORY.

It is well known that American geologists have taken a very prominent part in the study of mountain structure and mountain origin. So much so indeed that the *lateral pressure theory* in the form given above and interior contraction as its cause, have sometimes been called the "American theory." It is also well known that my name, among others, especially Dana's, has been associated with this view. All I claim is to have put the whole subject, especially the formal theory, in a clearer light and more consistent form.[1] The formal theory I regard as a permanent acquisition. The contractional theory may not be so. It is natural, from my long association with it, that I should be reluctant to give it up. But I am sure that I am willing to do so if a better can be offered. We all dearly love our own intellectual children, especially if born of much labor and thought; but I am sure that I am willing, like Jephtha of old, to sacrifice, if need be, this my fairest daughter on the sacred altar of Truth. Objections have recently come thick and fast from many directions. Some of these

[1] "Theory of the Formation of the Great Features of the Earth's Surface." Am. Journal, Vol. 4, pp. 345 and 460, 1872, and also "Structure and Origin of Mountains," Vol. 16, p. 95, 1878.

I believe can be removed ; but others perhaps cannot in the present condition of science, and may indeed eventually prove fatal. Time alone can show. I state briefly some of these objections.

1. Mathematical physicists assure us that on any reasonable premises of initial temperature and rate of cooling of the earth, the *amount* of lateral thrust produced by iuterior contraction would be wholly insufficient to account for the enormous foldings.[1] Let us admit—surely a large admission—that this is so. But this conclusion rests on the supposition that the whole cause of interior contraction is *cooling*. There may be other causes of contraction. If cooling be insufficient, our first duty is to look for other causes. Osmund Fisher has thrown out the suggestion (a suggestion by the way highly commended by Herschel) that the enormous quantity of water vapors ejected by volcanoes and the probable cause of eruptions is not meteoric in origin as generally supposed, but is original and constituent water occluded in the interior Magma.[2] Tschermak has connected this escape of constituent water from the earth with the gaseous explosions of the sun.[3] Is it not barely possible that we may have in this an additional cause of contraction, more powerfully operative in early times but still continuing? See the large quantity of water occluded in fused lavas to be "*spit out*" in an act of solidification! But much still remains in volcanic glass which by refusion intumesces into lightest froth. Here then, is a second possible cause of contraction. If these two be still insufficient, we must look for still other causes before rejecting the theory.

2. Again: Dutton[4] has shown that in a *rigid earth* it is impossible that the effects of interior contraction should be concentrated along certain lines so as to form mountain ranges, because this would require a shearing of the crust on the interior. The yield-

[1] Cam. Phil. Trans. Vol. XII., Part II., Dec. 1873.

[2] Cambridge Phil. Trans. Vol. XII., Part II., Feb. 1875. Physics of the Earth's Crust, p. 87.

[3] Geol. Mag. Vol. IV., p. 569, 1877.

[4] Am. Jour. Vol. VIII., p. 13, 1874. Penn. Monthly, May, 1876.

ing according to him would be evenly distributed everywhere and therefore imperceptible anywhere. This is probably true, and therefore a valid objection in the case of an earth *equally rigid in every part.* But if there be a sub-crust layer of liquid or semi-liquid or viscous, or even more movable or more unstable matter, either universal or over large areas, as there are many reasons to think, then the objection falls to the ground. For in that case there would be no reason why the effects of general contraction should not be concentrated on weakest lines as we have supposed.

3. But again: it has been objected that the lines of yielding to interior contraction ought not to run in *definite* directions for *long distances*, but irregularly in *all* directions. I believe we may find the answer to this objection in the principle of flow of solids under very slow heavy pressure. The flow of the solid earth, under pressure in *many* directions, might well be conceived as being deflected to the direction of least resistance, *i. e.*, of easiest yielding.

4. But again: it will be objected that the amount of circumferential shortening necessary to produce the foldings of some mountains is simply incredible; for it would disarrange the stability of the rotation of the earth itself. According to Claypole, in the formation of the Appalachian range, the circumference of the earth was shortened eighty-eight miles and in the formation of the Alps seventy-two miles. Now this would make a decrease of diameter of the earth of twenty-eight miles in the one case and twenty-three in the other. This would undoubtedly seriously quicken the rotation and shorten the day. This seems indeed startling at first. But when we remember that the tidal drag is all the time retarding the rotation and lengthening the day and much more at one time than now, we should not shrink from acceptance of a counteracting cause hastening the rotation and shortening the day, and thus giving stability instead of destroying it. We must not imagine that there would be anything catastrophic in this readjustment of rotation. Mountains are not formed in a day nor in a thousand years. It requires

hundreds of thousands of years, or even millions of years—if physicists allow us so much.

The objections thus far brought forward, though serious, are by no means unanswerable. But there is one brought forward very recently which we are not yet fully prepared to answer and may possibly prove fatal.

5. *Level of No Strain.*—Until recently the interior contraction of the earth was considered only roughly and without analysis. It was seen that the surface was already cool and its temperature fixed while the interior was still hot and cooling; and therefore that the exterior must be thrust upon itself and be crushed. But the phenomena are really far more complex than at first appears. It is necessary to distinguish between two kinds of contraction to which the interior layers are subjected, viz., radial and circumferential. If there were radial contraction only, then undoubtedly every concentric shell as it descended into smaller space would be crushed together laterally. But there is for all layers, except the surface, also a circumferential contraction, and this would have just the opposite effect, *i.e.*, would tend to stretch instead of crush. Therefore wherever the decrease of space by descent is greater than the circumferential contraction, there will be crush, and where the circumferential contraction is greater than the decrease of space by descent, there will be tension and tendency to crack. There would be no *real* cracking, only because incipient cracks would be mashed out or rather prevented by superincumbent pressure. Where these two are equal to one another, there will be no strain of any kind. There is a certain depth at which this is the case. It is called the "*level of no strain.*" To Mellard Reade is due the credit of first calling attention to this important principle.

Let us analyze the principle more closely. It is admitted that at the surface there is no contraction of any kind. It is also calculated that contraction of all kinds cease at depth of 400 miles. It is believed farthermore that commencing 400 miles below the surface and coming upward the contraction increases very slowly from zero to a maximum at the depth of 70 miles

and then decreases again more rapidly to zero at the surface. This is shown in diagram, Fig. 1. In this figure the curve represents the relative rate of contraction whether radial or circumferential of the several layers. We use it, however, only to represent the latter. For in considering the radial contraction, it is not the relative rate of the several layers that immediately concerns us, but their rate of *radial descent.* Now this is a *summation series* and therefore increases to the very surface, but at different rates of increase. The law of increase of radial descent as we come toward the surface is shown in diagram, Fig. 2[1] in which the rate of increase is greatest at seventy miles, just where the curve changes from concavity to convexity. If now we superpose these two diagrams the depth *a* at which the two curves,

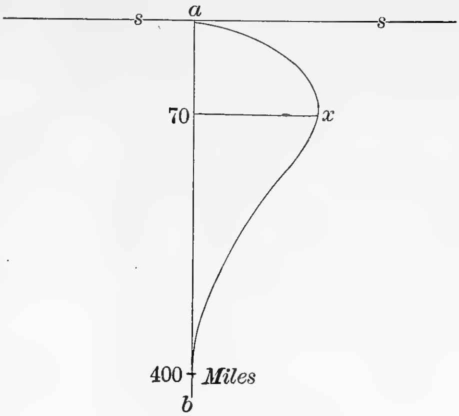

FIG. 1. *s s*=Surface; *a b*=depth along radius; *a x b*= curve of contraction.

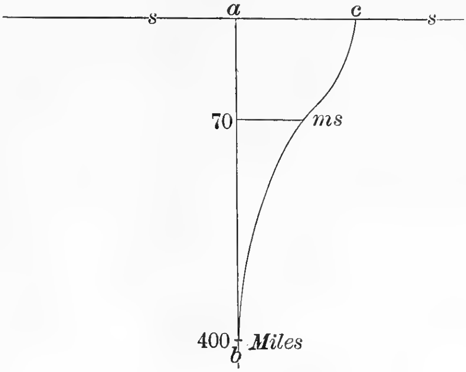

FIG. 2. *c b*=curve of radial descent.

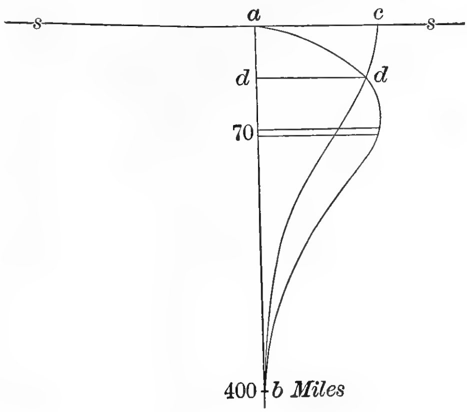

FIG. 3. *d d*=level of no strain.

[1] I have taken these figures from Claypole, but modified this one so as to make it a truer representation of the law.

viz., that of circumferential contraction and that of radial descent, intersect, is the level of no strain.

Now laborious calculations have been made by Davison, Darwin and Fisher to determine the depth of this level of no strain. All make it very superficial. Davison, taking an initial temperature of 7000° F., makes it five miles below the surface. Fisher, on the same data, only two miles, and with an initial temperature of 4000° only *0.7* of a mile. It is easy to see that if this be true, the amount of lateral thrust must be small indeed.

Now undoubtedly there is a true principle here which must not hereafter be neglected, but it is almost needless to say that these quantitative results are in the last degree uncertain. The calculations are, of course, based on certain premises. These are a uniform initial temperature of say 7000° F., a time of cooling, say 100 or 200 millions of years, and a certain rate of cooling under assumed conditions. The depth of the level of no strain increases with the time and is still going downward. In a word, in a question so complex both mathematically and physically and in which the data are so very uncertain, every cautious geologist, while freely admitting the soundness of the principle, will withhold assent to the conclusions. Huxley has reminded us that the mathematical mill, though a very good mill, cannot make wholesome flour without good wheat. It grinds indifferently whatever is fed to it. It has been known to grind peas cods ere now. It may be doing so again in this case. Let us wait.

But besides withholding assent and waiting for more light, I may add that these calculations, of course, go on the supposition that the whole contraction of the earth is due to loss of heat; but as we have already said, it may be due also to loss of constituent water. This would put an entirely different aspect on the subject.

ALTERNATIVE PHYSICAL THEORIES.

I have given the objections to the contractional theory frankly and I think fairly. They are undoubtedly serious. Let us see what has been offered it its place.

I. READE'S EXPANSION THEORY.

This, the most prominent among alternative theories, was first brought forward in Mr. Reade's book on "Origin of Mountain Ranges." Although I have carefully read all that Mr. Reade has written on the subject, I find it difficult to get a clear idea of his views. But, as I understand it, it is in outline as follows: (1) Accumulation of sediments off shore and isostatic subsidence of the same. (2) Rise of isogeotherms and heating of the whole mass of sediments and of the underlying crust in proportion to the thickness of the sediments. (3) *Expansion* of the whole mass in proportion to the rise of temperature. If there were no resistance, this expansion would be in all directions (cubic expansion). (4) But since the containing earth will not yield to expansion laterally, this lateral expansion is satisfied by *folding*, and this in turn produces *vertical upswelling*. Thus the whole *cubic expansion is converted into vertical expansion*, which is therefore three times as great as the linear expansion in any one direction. (5) Elevation would of course anyhow be greatest along the line of thickest sediment; but this by itself would not be sufficient to produce a mountain. (6) But farther—and here the theory is more obscure—there is a concentration of the effects of expansion, along a comparatively narrow line of thickest sediment, by a *flow* of the hydrothermally plastic or even liquid mass beneath, *toward* this central line and then *upward* through the parted strata, folding these back on either side and appearing at the crest as the granitic or metamorphic axis. (7) In his latest utterances he seems to adopt the view of Reyer, viz., that the uplifted strata slide back down the slope, producing the enormous crumpling so often found, and exposing a wider area of granite axis. (8) From the same liquid mass which lifts the mountain, come also the great fissure eruptions and the volcanoes.

Mr. Reade makes many experiments to determine the linear expansion of rocks, and he thinks that these experiments show that when cubic expansion is converted into vertical expansion and this again concentrated along a line one-fourth to one-fifth the whole breadth of the expanding mass, it would explain the

elevation of the highest mountains. But still he seems uncertain if it be enough. In fact, he declares that if it were not for another factor yet unmentioned, he probably would never have brought forward the theory at all.

(9) This factor is *recurrency of the cause and accumulation of the effects.* And here the previous obscurity becomes intensified. I have read and re-read this part without being able wholly to understand him. He seems to think that when expansion had produced elevation, the mountain thus formed would not come down again by cooling and contraction; but on the contrary would *wedge up by normal faulting and set in its elevated position.* Afterward, by new accumulation of heat, another elevation and setting would take place and the mountain grow higher, and so on indefinitely, or until the store of heat is exhausted. Therefore he characterizes his theory as that of "*Alternate expansion and contraction,*" or again as that of "*Cumulative recurrent expansion.*"

Such is a very brief, perhaps imperfect, but I hope fair outline of Reade's theory. It seems to me that there are fatal objections to it. These I now state.

Objections.—1. The first is *inadequacy* to account for the enormous foldings of the mountains especially when there is no granite axis to fold back the strata. It is true that Mr. Reade makes comparison between his own and the contractional theory in this regard, and seems to show the much greater effectiveness of his own. This may be true if we accept his premises and compare *equal areas* in the two cases. But the contractional theory *draws from the whole circumference* of the earth and *accumulates* the effects on one line, while in Reade's theory the expansion is, of course, very *local.*

2. But the fatal objection is that brought forward by Davison. It is this: sedimentation cannot, of course, increase the sum of heat in the earth. Therefore the increased heat of the sediments by rise of isogeotherms, *must be taken from somewhere else.* Is it taken from below? Then the radius below must contract as much as the sediments expand and therefore there will be no elevation. Is it taken from the containing sides? Then

the sides must lose as much as the sediments gain, and therefore must contract and make room for the lateral expansion, and therefore there would be no folding and no elevation. I do not see any escape from this objection.

Thus it seems that Reade's theory cannot be accepted as a substitute. Is there any other?

II. DUTTON'S ISOSTATIC THEORY.[1]

Dutton's discussion of isostasy is admirable, but his application of it to the origin of mountains is weak. The outline is as follows:

Suppose a bold coast line, powerful erosion and abundant sedimentation. The coast rises by unloading and the marginal sea-bottom sinks by loading. Now if isostasy is perfect, there will be no tendency to mountain formation. But suppose a piling up of sediments, but—on account of earth rigidity—without immediate compensatory sinking, and a cutting down of coast land without compensatory rising. Then *there would be an isostatic slope toward the land.* And the accumulated and softened sediments would *slide landward, crumpling the strata and swelling them up into a mountain range.*

The fatal objection to this view is that complete isostasy is necessary to renew the conditions of continued sedimentation and therefore to make thick sediments, otherwise the sediments quickly rise to sea-level and stop the process of sedimentation at that place. But it is precisely a *want* of complete isostasy which is necessary to make an isostatic slope landward. Dutton refers to Herschel as having suggested a similar cause of strata crumpling and slaty cleavage[2]; but the principles involved in the two cases are almost exactly opposite. Herschel supposes sediments to slide down steep *natural* slopes of sea-bottoms and therefore *seaward.* Dutton supposed sediments to slide *up* natural, though *down* isostatic slopes, *landward.* Herschel's is a theory of strata-

[1] Phil. Soc. of Washington, Bull. Vol. XI, pp. 51–64, 1889.

[2] Phil. Mag., Vol. 12, 197, 1856.

crumpling and slaty cleavage; Dutton's a theory of mountain formation.

There has been no attempt to carry this idea of Dutton's to quantitative detail. It was probably thrown out as a suggestion in mere despair of any other explanation, for he had already repudiated the contractional theory. But the least reflection is sufficient to convince that such slight want of complete isostatic equilibrium as may sometimes occur would be utterly inadequate to produce such effects.

III. REYER'S GLIDING THEORY.[1]

Prof. Reyer has recently put forward certain views fortified by abundant experiments on plastic materials. His idea in brief seems to be this: Strata are lifted and finally broken through by up-rising fused or semi-fused matters and these appear above as the granitic axis. As the axis rises, the strata are carried upward on its shoulders, until *when the slope is sufficiently steep the strata slide downward crumpling themselves into complex folds* and exposing the granitic axis in width proportioned to the amount of sliding.

No doubt there is much value in these experiments of Reyer, and possibly such gliding does indeed sometimes take place in mountain strata and some foldings may be thus accounted for. But the great objections to this view are (1) that there is no adequate *cause* given for the *granitic uplift*, and (2) that it utterly fails to account for the complex foldings of such mountains as the Appalachian and Coast Range *where there is no granite axis at all*. Reade, indeed, holds that the Piedmont region is the granite axis of the Appalachian, and that the original strata of the eastern slope are now buried beneath the sea. But American geologists are unanimous in the belief that the shore line of the great interior Palæozoic sea was but a little east of the Appalachian crest and the sea washed against land of Archæan rocks extending eastward from that line.

[1] Nature, Vol. 46, p. 224, 1892, and Vol. 47, p. 81, 1892.

CONCLUSION.

After this rapid discussion of alternative theories in which we have found them all untenable, we return again to the contractional theory, not indeed with our old confidence, but with the conviction that it is even yet the best working hypothesis we have.

JOSEPH LE CONTE.

ON THE MIGRATION OF MATERIAL DURING THE METAMORPHISM OF ROCK-MASSES.

THE researches of numerous geologists during the last two decades have placed at our disposal a large amount of information respecting the metamorphism of rocks, and from the facts thus collected we are now in a position to draw conclusions which we may expect to have a wide application. The important changes that affect the character of rock-masses divide roughly into two classes.

First, there are those dependent on meteoric agencies. These changes, though not necessarily superficial in the ordinary sense, are due in the first place to the action of circulating waters in communication with the atmosphere, and as a rule they involve the addition or subtraction of various ingredients or the transference of material from one place to another. The ordinary "weathering" effects illustrate the removal of alkalies and silica, the addition of water, oxygen, carbonic acid, etc. We must also include the processes which have given rise to many crystalline limestones and quartzites, serpentine-rocks, dolomites, ironstones, and jaspers, and even (as appears from Van Hise's researches in the Penokee region) some mica-schists and fine-grained gneisses. The characteristic of almost all these transformations is that they are metasomatic as well as metamorphic.

Secondly, we have those transformations more usually understood by the term metamorphism : viz., dynamic metamorphism, due to high pressure operating upon rock-masses, and thermal metamorphism, due to high temperature, whether produced by an intrusion or by the mechanical generation of heat. In these various cases of metamorphism proper, metasomatism is rather the exception than the rule. I shall deal here with thermal metamorphism only, and shall draw my data chiefly from the rocks surrounding the large igneous intrusions of the English Lake District, investigated by Mr. Marr and myself, but the conclusions are confirmed in other areas.

Metasomatic changes are known to take place during thermal metamorphism as regards the *volatile* constituents of the rocks affected. A (usually partial) loss of water and the elimination (under proper conditions) of carbonic acid from carbonates are instances of this; a more special case is the accession of boric and hydrofluoric acids near the contact of metamorphosed rocks with certain acid intrusives. Several observers have recorded a transference of other materials (silica and soda) from an invading igneous magma to the neighboring rocks, but such a phenomenon seems to be of uncommon occurrence, and to be confined to the immediate vicinity of the contact. Apart from the exceptions noted, there is every reason to believe that thermal metamorphism involves no alteration in the bulk-analysis of the rocks affected. Whatever part water may play in the various chemical changes that are set up, it does not (as in atmospheric metamorphism) act as a medium to transfer material to or from the rocks in question.

I believe that we can go further, and assert that within the mass of a rock undergoing thermal metamorphism any transference of material (other than volatile substances) is confined to extremely narrow limits, and consequently that, for a given temperature of metamorphism, the mineral formed at any point depends only on the chemical composition of the rock-mass within a certain very small distance around that point. Illustrations of this principle, as stated in the latter form, are familiar to all who have studied cases of "contact metamorphism":[1] they are very striking when some of the constituent substances of the original rock were, by weathering or otherwise, locally aggregated prior to metamorphism. By studying such cases we can not only verify the principle here laid down, but also arrive at an estimate of the actual limits within which interchange of material has taken place.

An excellent test-case is afforded by rocks containing calcite. It is well known that impure calcareous rocks are readily metamorphosed by heat into rocks rich in lime-silicates, with total

[1] Compare Bull. Geol. Soc. Amer. (1891) vol. iii., pp. 16–22.

elimination of the carbonic acid, while pure limestones or dolomites, under the same conditions, merely recrystallize without chemical change. In other words, the carbonates are decomposed in thermal metamorphism only in the presence of silica in some available form to take the place of the carbonic acid. Interesting illustrations of this are given by some of the rocks which have come under our notice.[1] The Strap granite in Westmoreland metamorphoses certain basic lavas containing amygdules of various dimensions, many of which were occupied, prior to the metamorphism, by calcite. Near the granite the smallest of these calcite-amygdules are converted into various silicates rich in lime, the silica having been derived from decomposition-products lining the original vesicles or from the immediately adjacent portion of the rock. In the larger metamorphosed amygdules, on the other hand, only the outer layers are transformed into lime-silicates, the interior still consisting of calcite; which, however, has recrystallized during the metamorphism, as is proved by its moulding the silicates and being penetrated by needles of actinolite, etc. Analogous appearances characterize veins and lenticles of calcite in shales and the converse case of argillaceous nodules imbedded in pure limestones and dolomites. The conclusion is that carbonic acid is displaced from the calcite only when there is in the immediate neighborhood either free silica or some substance capable of furnishing silica. Where calcite and quartz have recrystallized side by side in a metamorphosed rock, they are always separated by some one or more lime-bearing silicates, but their distance apart may be very small, and we deduce that the migration of silica to take the place of carbonic acid has been restricted to extremely narrow limits. In some highly altered rocks the distance is not more than one-twentieth of an inch.

The limit of migration of material no doubt increases with the temperature of metamorphism. This is well illustrated by some calcareous ashes or tuffs. At a considerable distance—say a thousand yards—from a large granite intrusion, the carbonic

[1] See especially Quart. Journ. Geol. Soc. (1893) vol. xlix., pp. 359–371.

acid is entirely expelled only from very fine-grained mixtures of calcareous and ashy materials: approaching the contact, the complete decomposition of the calcite is found to extend to successively coarser-grained rocks. Another line of inquiry is offered by the texture of the metamorphosed rocks themselves, of whatever lithological nature, in a district of metamorphism surrounding a large igneous intrusion. The size of the individual crystals of secondary minerals increases towards the contact with the intrusive rock: this may be taken to indicate that the migration of material within the mass of a rock undergoing metamorphism has more latitude when the temperature is higher. For various reasons, however, it would be unsafe to found numerical results upon such observations. The crystals of certain metamorphic minerals attain to considerable dimensions by virtue of their power of enclosing a large amount of foreign material; others, again, can apparently push aside solid impurities to make room for their own growth. The texture of the metamorphic rocks examined is still, however, in general accord with the conclusions reached by other methods of inquiry.

The question naturally arises whether the limit of migration of material is the same for different substances. On this point we have but little information. Among the various types of "spotted" rocks described in aureoles of metamorphism is one in which the spots are simply spaces free from the secondary brown mica abundant in the general mass of the metamorphosed rock. Since the iron compounds in the rock must originally have had a generally uniform distribution, the phenomena of the spots indicate a movement of ferrous oxide, and the radius of the spots gives a measure of the extreme limit of such movement. In the cases examined this is about one-twentieth of an inch, and we may infer that the greatest distance of migration of ferrous oxide has been about the same as that of silica at a similar temperature.

Not to insist unduly upon precise estimates, these and similar observations certainly tend to show that in thermal metamorphism no interchange of material takes place except between

closely adjacent points. The law that, apart from volatile constituents, the total chemical composition remains unchanged is true not only of the rocks in bulk, but of any individual cubic inch of the rocks. This might be followed out into various corollaries, of which I note only one, viz., that the greatest variety of metamorphic minerals is to be found in rocks which were the most heterogeneous prior to metamorphism. Such rocks are breccias and fault-breccias, etc., and especially basic igneous rocks more or less weathered before being metamorphosed.

ALFRED HARKER.

CAMBRIDGE, ENGLAND.

THE CORDILLERAN MESOZOIC REVOLUTION.

CERTAIN features connected with the occurrence of plutonic rocks on the western side of America suggest hypotheses which have an important bearing upon our general conceptions of the structural development of the continent. These features are but imperfectly and very partially recorded thus far in geological literature, owing to the vastness of the field and the meagre amount of investigation which has been devoted to it. Yet enough facts have been accumulated to have impressed the writer that they point to generalizations which have not yet been fully presented for the consideration of students of continental problems. To formulate these generalizations is the object of this brief note. It is not the purpose of the writer to add to the record of facts so much as to connote the more important of them and to suggest their cumulative significance.

The researches of Richardson[1] and Dawson[2] on the coast and islands of British Columbia have shown that the Cretaceous rocks of that region, ranging from the *Aucella* bearing horizon (Neocomian) to the Chico, repose upon a profoundly eroded complex of granite and metamorphic rocks. The disturbances which have affected these Cretaceous strata since their deposition have been of a local rather than of a regional character. They lie upon the old basement usually in but little disturbed attitudes, or are inclined at low angles, though occasionally they are faulted or sharply folded along certain lines of post-Cretaceous movement. The same condition seems to generally characterize the more elevated early Cretaceous rock of the British Columbian interior along the cañon of the Fraser river. Jurassic rocks have been described from British Columbia, but the Geological Survey of Canada has since come to the conclusion that these rocks are

[1] Reports of Progress, Geol. Survey of Canada, 1871–2, 1872–3, 1873–4, 1874–5, 1876–7.

[2] Report of Progress, Geol. Survey of Canada, 1878–9. Annual Report (New Series) Vol. II., 1886. Geol. Survey of Canada, Report B.

Cretaceous.[1] If the Jurassic exists on the west coast of British Columbia, it must occupy very limited areas or be involved in the pre-Cretaceous metamorphic complex. The fossils collected in the less altered portions of this complex by Richardson and Dawson, show the presence of Triassic and Carboniferous formations, but no undoubted Jurassic forms have yet been detected. It therefore seems that the erosion to which the region was subjected prior to the deposition of the Cretaceous was effected in Jurassic time. As Dawson has shown,[2] this erosion was of longer duration in the southern part of the province than in the northern, and the transgression of the Cretaceous sedimentation was from north to south.

The further studies of Dawson upon the pre-Cretaceous complex of granite and metamorphics have been fruitful of most interesting and important results. Prior to his researches the granite (and granite-gneisses) of the region were generally regarded as the equivalent of the Laurentian of the east. It was shown,[3] however, by him that the basement upon which the now metamorphic sedimentary and volcanic strata of the Vancouver series (Triassic, with probably some Carboniferous), was deposited is non-existent, and has been replaced by an immense mass of intrusive granite, which has absorbed by fusion all rocks below the present remnants of the Vancouver series, and has invaded the latter after the manner of an irruptive magma. This post-Triassic granitic batholite is of enormous dimensions. In the fall of 1890 the writer had an opportunity of examining it cursorily for a distance in a straight line of over five hundred miles, in and out of the fiords of the coast from Burrard Inlet to Alaska; and the granite is known to extend far northward into that territory. Its width may be placed at from sixty to one

[1] Sketch of the Geology of British Columbia, by G. M. Dawson, Geol. Mag., April and May, 1881.

[2] Am. Jour. Sci., Vol. xxxix., March, 1890.

[3] Annual Report (New Series), Vol. ii., 1886, Geol. Survey of Canada, Report B, pp. 10-13.

hundred miles. In the portion examined there are several masses or belts of schistose metamorphic rocks which have been sunk down into the granite, but they form a small proportion of the entire complex. The granite varies somewhat in mineralogical composition, texture, and structure, and is often distinctly gneissic locally. In places it is essentially hornblendic, in others it is micaceous. Notwithstanding these variations, which are common in most large granite masses, the granite seems to be a unit throughout, and the mass is certainly a very important factor in the epeirogeny of the west coast of America. Even should it be discovered by the closer scrutiny which science will certainly demand, that there are portions of an older granite terrane to be discriminated from the general mass, the conclusion will not be invalidated, that in the interval between the deposition of Triassic strata and the deposition of lower Cretaceous, the earth's crust was in this region invaded by an immense batholitic magma, hundreds of miles in extent, which absorbed a large part of the pre-Triassic basement, as well as a portion of the Triassic rocks themselves. This invasion of the crust by the British Columbian batholite seems to have conditioned a general and pronounced elevation of the coast. For the erosion which intervened before the deposition of the Cretaceous was possessed of a vigor only born of lofty mountains, removing the upper crust and cutting down deep into the congealed granite. The Cretaceous rocks were littoral deposits at the base of these lofty mountains. Thus was a great revolution wrought in the geology and physiography of the west coast of British Columbia in the interval between the Triassic and Cretaceous times.

Little is definitely known of the geology of the Olympic Mountains, but it is probable that the conditions which prevail on Vancouver Island, which is the northern extension of the range, hold good here, the Cretaceous rocks of the coast reposing upon the lower flanks of mountains which consist of a complex of granite and metamorphic rocks. These mountains are probably the least known portion of the United States, and they are mentioned here simply to indicate that important evidence

bearing upon the phenomena here discussed is likely to be found in that region.

In southern Oregon, on the line of the Southern Pacific Railway, the writer has on several occasions observed the eruptive contact of an extensive granite mass against sedimentary strata which have been mapped as "Auriferous slates," which are probably early Mesozoic or Carboniferous in age. The intrusion of the granite into the sedimentary rocks is unquestionable, the relations being well exhibited in the excellent exposures afforded by the railway cuttings.

In California the statements of Whitney[1] and the more recent writings of the geologists of the U. S. Geological Survey, Diller, Becker, Turner, and Lindgren, and of Mr. H. W. Fairbanks, seem to leave no room for doubt that a great part, probably the greater part, of the granitoid rocks of the Sierra Nevada is of Mesozoic age, and has invaded the now more or less altered sedimentary and volcanic rocks known as the "Auriferous slates," which range in age from the Silurian up to the Jurassic.

Here again we have clearly to deal with a granitic batholite which must, by absorption or otherwise, have replaced a large portion of the preëxisting lower rocks in the region affected. From the facts recorded by able and critical observers, this conclusion holds, notwithstanding the probability that there may also be remnants of an older granite to be discriminated from the Mesozoic mass. In the southern Sierra, as Becker has, with wise caution, pointed out, we approach the region of Archæan granite known in the Grand Cañon section. It would therefore be not at all remarkable to find these more ancient granites involved with the newer in the Sierra Nevada. But their presence could not affect the important fact of an invasion of the crust during middle Mesozoic time by an immense granitic batholite, which invasion without doubt had much to do with the metamorphism of the strata which survived the upward progress of the magma into the crust.

Here again the development of the batholite seems to have

[1] Geology of California, Vol. I. Auriferous Gravels.

conditioned the uplift and wide-spread disturbance which is freely recognized in geological literature as having occurred at the close of the Jurassic. Again we have, as in British Columbia, a wonderful dissolving of the ancient *status quo*, a revolution of no mean import, whether regarded merely as an historical event or in its bearing upon the general principles of epeirogeny. The important feature which distinguishes the group of facts observed in the Sierra Nevada from those in British Columbia is that in the former we have the Jurassic a part of the great assemblage of rocks invaded by the granite while in British Columbia these rocks are not known to exist. This difference, taken together with the probable fact that the pre-Cretaceous denudation of the Sierra was less profound than that of British Columbia, suggests a progressive development of the batholitic condition from north to south, so that the disturbance was felt somewhat later in California, although it was part, doubtless, of the same great subcrustal process.

In the Coast Ranges of California we have much less precise information than in the case of the Sierra Nevada. Analogous conditions seem to be indicated by the information at hand. There are areas of granite and metamorphic rocks which have been subject to great denudation prior to the deposition of the Cretaceous. No rocks of older age than Cretaceous are known to rest upon the worn surface of this complex. Carboniferous fossils have recently been found by Mr. Fairbanks in the Santa Ana Range[1] in a series of rocks into which the granite of the region has been injected. The same geologist informs us of the intrusion of the granite of the Gavilan Range[2] into the Coast Range metamorphics, and of similar relations in the Trinity Mountains in the Northern part of the state.[3] The writer, also, has observed that the granite of the Santa Cruz Range is intrusive in the limestone of the metamorphic complex. Mr. Fairbanks is of the opinion that generally the

[1] Am. Geologist, vol. xi., Feb., 1893.

[2] Loc. cit.

[3] Am. Geologist, March, 1892.

granite of the Coast Ranges is the equivalent of that of the Sierra, but direct evidence of its intrusion into Triassic or Jurassic strata has not yet been adduced. All that can safely be asserted at present, in the opinion of the writer, is that in the Coast Ranges there is a pre-Cretaceous complex of granite and metamorphic rocks analogous to that of the Sierra Nevada; and that there is no evidence yet recorded which is adverse to Mr. Fairbank's correlation of the granites of the two regions.

In Mexico the official map shows conditions which resemble those of the Sierra Nevada. Emerging from beneath the volcanic sheets, or the mantles of Tertiary or Quaternary formations there are, along the western side of the Republic, numerous masses of granite rocks with associated metamorphics. In these metamorphic rocks are occasional patches of Jurassic and Triassic, conservatively limited in the mapping doubtless to the actual areas where fossils have been found to so determine their age. These small patches of known Jurassic and Triassic age are suggestive of the proximate limit in age of the metamorphic series, and yielding to analogy we may be allowed to *suppose* that the granite bears a relation to the Mexican metamorphics similar to that exhibited in the Sierra Nevada of California.

In South America Steinmann[1] calls attention to the important fact of the invasion of the Mesozoic strata of the Cordillera by truly granitic and dioritic rocks. Karsten,[2] also, informs us that in Columbia, Venezuela and Ecuador the Jurassic are the oldest sedimentary rocks, but have been found at only one locality, while the Cretaceous and Tertiary are abundantly developed; and that the underlying basement upon which the Cretaceous rests is largely granitic. Putting Steinmann's and Karsten's information together we seem clearly to have the conditions of British Columbia and California repeated as to the development of a granitic batholite in the Cordilleran belt in pre-

[1] Am. Naturalist, Oct. 1891.

[2] Geologie de l'Ancienne Colombie Bolivarienne, Nouvelle Grenada et Ecuador, par Hermann Karsten, Berlin.

Cretaceous Mesozoic time, followed by continental uplift and great denudation.

From the facts above cited certain conclusions seem to be warranted which may be presented in the form of hypotheses for future examination:

(1) The pre-Cretaceous Mesozoic revolution which has been freely recognized by nearly all Californian geologists was not limited to the western United States, but affected the entire extent of the Cordilleran belt from Alaska to South America.

(2) It is not clear that the revolution was strictly synchronous in all portions of the Cordilleran belt which have been affected. It may have been progressive, and have extended through the time from the close of the Triassic to the close of the Jurassic so as to obliterate the Jurassic seas earlier in some regions than in others.

(3) An essential feature of the revolution was the development of batholitic magmas which invaded the crust, replaced large portions of it, and eventually congealed as plutonic rock of a prevailingly rather acid character.

(4) The development of the batholite, or batholites, was followed or accompanied by continental uplift.

(5) The complex of invading granite and consequent metamorphics is analogous to that of the Archæan and indicates that the conditions which are commonly recognized as Archæan are not peculiar to rocks of that age.

By way of addendum to this brief note it should be remarked that the irruption of granite in South America did not wholly cease with the Mesozoic revolution. Farther south than the countries which have been mentioned, in the Cordillera of the Argentine Republic, Stelzner has shown that this phase of crustal development continued through into the Tertiary. After a narration and discussion of his facts he formulates the following conclusion:

"So mit bleibt denn nur noch die Annahme übrig, dass die als Granite, Syenite und Diorite zu bezeichnenden Andengesteine eruptive Gebilde sind, die theils nach der Jura- und Kreidezeit,

z. Th. sogar erst nach der in der Tertiärzeit erfolgten Ablagerung der buntscheckigen Andesittuffe im gluthflüssigen Zustande emporgestiegen sind und diejenigen Lagerungsverhältnisse eingenommen haben, unter welchen wir sie heute beobachten können."[1]

ANDREW C. LAWSON.

BERKELEY, July 15, 1893.

[1] Beitrage zur Geol. und Palaeont. der Argentinischen Republic, I. Geol. Theil, p. 207.

THE BASIC MASSIVE ROCKS OF THE LAKE SUPERIOR REGION.

III. SKETCH OF THE PRESENT STATE OF KNOWLEDGE CONCERNING THE BASIC MASSIVE ROCKS OF THE LAKE SUPERIOR REGION.[1]

WITHOUT attempting to distinguish critically between the different types of the basic rocks occurring in the Lake Superior region, it will be sufficient for the present to call attention to some of the work done on them, more especially with reference to their microscopical examination. It will not be necessary to refer to all of the articles in which the "traps" of the region have been more or less briefly mentioned, as it will serve our present purpose to allude only to the most important papers on the subject, and to outline, where advisable, the descriptions of the most important rocks as given by various authors. Professor Irving[2] has discussed the theories held by some of the writers with respect to the origin of the traps, but since these, when they differ from the generally accepted theory of an igneous origin for the rocks in question, are found to be opposed to the facts observed, it would be unprofitable to discuss them further. There can be no doubt but that all of the basic, massive rocks found in dykes and beds in the Lake Superior region are truly igneous.

Douglass Houghton[3] first called attention to the wide-spread occurrence of traps around Lake Superior in his Fourth Annual Report as Geologist of Michigan. He identified knobs, dykes and flows of trap, but was unable to distinguish between the numerous varieties of the rock. His observations related principally to the traps in the Archæan and Keweenawan areas in Michigan.

[1] This Journal, Vol. I., p. 433.

[2] The Copper-Bearing Rocks of Lake Superior. Monographs U. S. Geological Survey, Vol. V., p. 7.

[3] Dated 1841. Reprint in Memoir of Douglass Houghton, by Alvah Bradish, Detroit, 1889, pp. 167–168, and 176–182.

Following Houghton, Messrs. Foster and Whitney[1] made an examination of the copper and iron regions of Michigan under the direction of the United States government. In their report on the copper lands, they described briefly the occurrences of dykes and flows of traps in the copper-bearing rocks of the south shore of the lake. Among them they distinguished compact, amygdaloidal, porphyritic, epidotic and brecciated varieties (pp. 69 and 70). In Part II. of the report, in their description of the iron region, they refer to the large dykes in the Animikie rocks on the north shore of the lake (pp. 12–13), and to the dykes of diabase cutting the Archæan schists in the neighborhood of Marquette, Michigan (pp. 18 and 39). They also gave a recapitulation of the characteristics of the traps of the entire region (pp. 85–94), with their chemical and mineralogical composition.

At about the same time that Messrs. Foster and Whitney were engaged in their survey of the copper and iron rocks, Dr. D. D. Owen,[2] with his assistants, was employed in making a geological reconnoissance of the states of Wisconsin, Iowa, and Minnesota. Messrs. D. D. Owen, J. G. Norwood, B. F. Shumard, Col. Whittlesey, and Major R. Owen examined a much larger area than did Messrs. Foster and Whitney, and were therefore not able to give as much detailed description of the rocks observed as the last named geologists succeeded in doing. They, however, mention the occurrence of sheet and dyke gabbros in Wisconsin, and of dyke gabbros in the Animikie of Minnesota.

Following these geologists came many others who examined the Lake Superior region in more or less detail, but added little to the knowledge of the trap rocks of the district, until, in 1871, Professor R. Pumpelly[3] published a paper on "The Paragenesis and Derivation of Copper and its Associates on Lake Superior," in which he described the melaphyres and other basic rocks associated with the copper on Keweenaw Point. After Pumpelly a number of geologists visited the region, but they devoted their

[1] Report on the Geology and Topography of a Portion of the Lake Superior Land District, Part I. Washington, 1850. Part II., Washington, 1851.

[2] Report of a Geological Survey of Wisconsin, Iowa, and Minnesota. By D. D. Owen. Philadelphia, 1852, pp. 142–164, 285, 304–306, 342–417.

[3] Am. Jour. Sci. (3) II., 1871, p. 188.

time principally to the discovery of the relations existing between the several rocks, and made no efforts to divide these into their varieties.

With the establishment of the surveys of Minnesota, Michigan, and Wisconsin, however, an attempt was made to classify with scientific accuracy the basic rocks of these three states. Kloos[1] had already discovered the gabbro of Duluth and had identified a melaphyre from the same place, but had made no very exact determination of either. Among the geologists on the Michigan and Wisconsin surveys, Messrs. Julien, Wright, Wichman, Pumpelly and Irving examined microscopically the rocks of the Huronian and the Keweenawan series of Wisconsin, and of the Archæan, Huronian and Keweenawan of Michigan, and among the descriptions of these rocks which they give may be found very exact accounts of the characteristics of the diabases, gabbros and other basic eruptives of the region.

Messrs. A. A. Julien[2] and C. E. Wright,[3] as early as 1873, mentioned quite fully the greenstones and traps of the Archæan and of the iron-bearing formations in Michigan. The former writer identified many massive and schistose rocks to which he gave the name of diorite, since he found in them hornblende, but no augite. Mr. Wright likewise discovered hornblende rocks which he evidently regarded as original, since he calls them all diorites. Mr. Wright's determinations are the first ones based upon microscopical observations of Lake Superior rocks. Messrs. Brooks[4] and Pumpelly[5] contented themselves with macroscopic examinations of the basic rocks of the iron and copper-bearing series in this state, and in this way distinguished diorites, melaphyres and amygdaloids, while Mr. Marvine[6] divided the

[1] J. H. Kloos: Geologische Notizen aus Minnesota. Zeits. d. deutsch. geol. Gesell. XXIII., 1871, p. 417. Trans. by N. H. Winchell, 10th Ann. Rep. Geol. and Nat. Hist. Survey of Minnesota, for 1881, p. 193.

[2] A. A. Julien: Geological Survey of Michigan, Vol. II., 1873, Appendix A, p. 41.

[3] C. E. Wright: Ib. Appendix C, p. 213–231.

[4] T. B. Brooks: Geological Survey of Michigan, Vol. I., 1873; Part I., Iron-Bearing Rocks, pp. 99–104.

[5] R. Pumpelly: Part II., Copper District, Ib. pp. 7–16.

[6] A. R. Marvine: Part II., Copper District, Ib. pp. 95–116.

rocks of the Eagle River section of Keweenaw Point into greenstone or fine-grained diorites, feldspathic traps or coarse grained diorites, and traps, including the melaphyres and amygdaloids.

Before the publication of the reports of the Wisconsin survey, Messrs. Streng and Kloos[1] communicated the results of their examination of certain Keweenawan rocks occurring in Minnesota and in Wisconsin about the head of Lake Superior. Streng, who did the microscopical work of the investigation, recognized among his specimens melaphyres, augite-diorites, quartz-diorites and a hornblende-gabbro to which reference has already been made in a former article.[2] Pumpelly[3] also had devoted his attention to the rocks of the copper series. He studied more particularly the fine and coarse-grained diabases and melaphyres of Keweenaw Point.

With the publication of Volume III. of the Geological Survey of Wisconsin a more general classification of the Keweenawan rocks of Northern Wisconsin and of Keweenaw Point in Michigan was given by the same author.[4] He distinguished among them diabases, hornblende and orthoclase-gabbros, melaphyres, augite-diorites and porphyrites, the characteristics of which will be mentioned when the discussion of the diabases and gabbros of Keweenawan age is taken up. In the same volume Irving described the rocks of the Huronian of Wisconsin, among which he found gabbros (p. 147), and those of the Keweenawan in the same state (pp. 168 to 193). The hornblende-gabbros and the augite-diorites of Pumpelly he regarded as altered gabbros and diabases, and not as original hornblende rocks. Julien[5] also gave a very excellent account of the microscopic appearance of two olivine-diabases

[1] A. Streng and J. H. Kloos: Ueber die Krystallinischen Gesteine von Minnesota in Nord Amerika. Neues Jahrb. f. Min., etc., 1877, pp. 31, 113, 225.

[2] This Journal, Vol. I., p. 447.

[3] R. Pumpelly: Metasomatic Development of the Copper-Bearing Rocks of Lake Superior. Proc. Am. Acad. of Arts and Sciences, 1878, XIII., Part II., pp. 253–309.

[4] Geology of Wisconsin, III., 1880, p. 29.

[5] A. A. Julien: Microscopic Examination of Eleven Rocks from Ashland county Wisconsin. Geol. of Wisconsin, III., 1880, p. 224.

from Ashland county, Wisconsin; and Wichman[1] published a classification of Huronian rocks based on their microscopical examination. Wichman divided the massive basic rocks into diabases, coarse-diabases and diorites. The only other microscopical work done in connection with the Wisconsin Survey is that by the late C. E. Wright, published in the second volume of the reports. In this Mr. Wright[2] mentioned the occurrence of a diorite containing augite in the bed of Black river.

Further, Dr. Wadsworth,[3] in his discussion as to the origin of the jasper and iron-ores of the Marquette region describes briefly the microscopic features of many of the intrusive knobs that are so prominent a feature in the topography of the district. These are declared to consist largely of diabase and coarse basalt, both massive and slightly schistose.

The investigation of the basic rocks of the region had by this time been sufficiently exact, and the number of specimens examined was large enough to give an idea of the characters of the commonest types occurring there, but these investigations had been undertaken by so many different geologists that no exact correlation between the various varieties discovered was possible. No classification of these could be accomplished until some had examined specimens from all the different localities and had compared them with one another. This work was undertaken by Professor Irving[4] in 1881, and was ably accomplished by him in the course of two years. All publications referring to the lithology of the Keweenawan and Huronian formations on both sides of the lake were carefully reviewed, most of the specimens described in them were examined, and the results of this study and examination, together with a great deal of new information gathered

[1] A. Wichman: Microscopical Observations of the Iron-bearing (Huronian) Rocks from the Region South of Lake Superior. Ib. p. 600.

[2] Charles E. Wright: Geol. of Wisconsin, II., 1878, p. 637.

[3] M. E. Wadsworth: Notes on the Geology of the Iron and Copper Districts of Lake Superior. Bull. Mus. Comp. Zoölogy, 1881, Vol. VII., p. 36–49.

[4] R. D. Irving: The Copper-bearing Rocks of Lake Superior. Monograph V., U. S. Geol. Survey, Washington, 1883.

during a trip among the dykes and sheets of the north shore of the lake, were incorporated in a monograph and published under the auspices of the U. S. Geological Survey in 1883.

The greater portion of the volume is concerned with the discussion of the Keweenawan rocks, but a brief synopsis of the character of the Huronian Series is given (pp. 367–409), and in this a few descriptions of Huronian basic eruptives are communicated. A brief synopsis of Irving's results will serve to give an idea of the relations of the different basic rocks to each other, and at the same time will serve as a basis for the present paper.

The original basic rocks of the Keweenawan, according to Irving, embrace gabbros and diabases, an anorthite rock consisting almost exclusively of anorthite, malaphyres and amygdaloids. The rocks described under the various names possess in general the characteristics of the respective types as defined by Rosenbusch in the first edition of his Massige Gesteine. The gabbros are coarse-grained rocks with a dark-gray or black color in the least coarse-grained varieties, and a light-gray color when the plagioclastic ingredient becomes greatly predominant as is apt to be the case in the coarser kinds. Their texture is highly crystalline, and their specific gravity varies between 2.8 and 3.1. The fine-grained basic rocks, whose ordinary type is diabase, make up relatively thin flows, that are almost invariably furnished with vesicular or amygdaloidal upper portions. Externally the diabases are dark in shade, being black, purple, dark green or brown, according as the rock has undergone more or less alteration. In texture they vary from medium fine-grained to cryptocrystalline. The coarser kinds grade into coarse-grained gabbros, but this gradation has never been observed in any one bed. Moreover, the diabases have undergone a great deal more alteration than the coarser gabbros, and are very strongly marked by their external characteristics, both in their fresh and altered states. They therefore seem to Irving to deserve a special name; since they possess the structure of diabases he calls them by this designation. The olivine-free diabases of the ordinary type pass into still finer grained kinds of a black or brown color. Some of these are

entirely aphanitic, and all kinds tend to a porphyritic development, carrying as phenocrysts oligoclase and more rarely labradorite and augite. Like the diabases mentioned above, the diabase-porphyrites are furnished with amygdaloidal upper portions. In the few instances in which the olivine-bearing rocks have an undifferentiated glassy base, they are called melaphyres, although placed among the fine-grained diabases.

The most of the basic rocks of the region are in the form of interbedded sheets. Dykes are rare. When they occur, their material appears to be diabase or diabase-porphyrite. It is rarely coarse enough to be classed with the rocks called gabbro.

In the Huronian areas on the other hand, large dykes of coarse-grained gabbros[1] cut through the sedimentary beds, and with these are intercalated thick beds of gabbro, and occasionally a few thinner ones of diabase.

Since Irving's general classification of the rocks in question a few other publications have appeared in which the petrography of small areas, and the descriptions of hand-specimens are treated.

Messrs. Herrick, Tight and Jones[2] busied themselves during one summer with a study of the rocks around Michipicoten Bay, an arm of Lake Superior extending northeasterly into Canada. Their paper contains but little with respect to the basic eruptives not found in Irving's monograph. Dr. Wadsworth[3] has examined some of the specimens gathered by the Minnesota Survey and has divided the basic rocks into peridotites, basalts, including gabbros, diabases, melaphyres, diorites and norites, peridotites, and rocks regarded as altered andesites. All of Dr. Wadsworth's descriptions are marked by exactness, but the conclusions based upon them are rendered less valuable than they would have been had Wadsworth himself not been compelled to depend upon others

[1] It will be shown later that most of the rocks called gabbro by Irving and others, are not gabbros, but are coarse-grained diabases.

[2] C. L. Herrick, W. G. Tight and H. Jones: Geology and Lithology of Michipicoten Bay. Bull. Scient. Lab. of Denison Univ., Vol. II., Part 2, 1887, p. 120.

[3] Dr. M. E. Wadsworth: Preliminary Description of the Peridotytes, Gabbros, Diabases and Andesytes of Minnesota. Bull. No. 2, Geol. and Nat. Hist. Survey of Minn., 1887.

for a knowledge of the field relations of the specimens studied. Messrs. Herrick, Clarke and Deming[1] have also studied a few specimens of the gabbro, both ordinary and orthoclastic varieties, from Duluth, but they have added little to what was already known concerning them, except the suggestion of the possible dependence of the orthoclase-bearing varieties upon their environment for the peculiar characteristics which they possess.

The Canadian geologists have likewise been engaged in a study of the rocks on the north side of Lake Superior. Many allusions have been made to the massive sheets and dykes in the Thunder Bay region, but no microscopical descriptions of them have been published, with the exception of a few notes by the present writer appended to a report by Mr. Ingall[2] on Mines and Mining in the Thunder Bay Silver District. In this report the relations of the large dykes and thick beds of diabase or gabbro to the fragmental rocks of the Animikie series north of the lake are carefully sketched, and the microscopic features of the most important rocks are described. In the Appendix,[3] a few altered gabbros and diabases from both sheets and dykes are very briefly characterized. The former of these have the general peculiarities of the gabbro from the great dyke on Pigeon Point, Minnesota, referred to by the writer[4] in an article on certain contact phenomena at this place, and described at greater length[5] in a bulletin of the U. S. Geological Survey. In the first of these two papers, in addition to the reference to the Pigeon Point dyke, a few remarks are made concerning the relations of Irving's orthoclase-gabbros to the more common varie-

[1] C. L. Herrick, E. S. Clarke and J. L. Deming: Some American Norytes and Gabbros. Am. Geol., June, 1888, p. 339.

[2] E. D. Ingall: Report on Mines and Mining on Lake Superior. Geol. and Nat. Hist. Survey of Cannda. Montreal, 1888.

[3] W. S. Bayley: Notes of Microscopical Examination of Rocks from the Thunder Bay Silver District.

[4] W. S. Bayley: A Quartz-Keratophyre from Pigeon Point and Irving's Augite-Syenites. Am. Jour. Sci. XXXVII., 1889, p. 54.

[5] W. S. Bayley: The Igneous and other Rocks on Pigeon Point, Minnesota, and their Contact Phenomena. Bull. No. 109, U. S. Geol. Survey, 1893.

ties of the gabbro of the region, but no detailed descriptions of these rocks, nor of the ordinary gabbros, whose modified forms they are supposed to be, are given. Finally, Dr. A. C. Lawson[1] has mentioned some of the characteristics of certain diabases from dykes in the Archæan rocks of the Rainy Lake region, in which the gabbroitic as well as the diabasic structures are well exhibited, the former toward the centers and the latter near the sides of the masses.

The most comprehensive treatment of the "greenstones" and "greenstone schists" of the Lake Superior region is that by Dr. G. H. Williams[2] in his bulletin on the origin of the green schist, supposed to underlie the Huronian in Michigan. In this volume the author not only describes the petrographical features of the schists with which he deals, but he likewise describes in some detail the microscopical characteristics of the diabases, diabase porphyrites, diorites, diorite porphyrites and gabbros, associated with the schists, and from some of which the latter have been derived.

Within the past three years a number of papers have appeared in which reference is made to some of the special features of a few of the coarse basic rocks, both north and south of the lake, but no articles have been published that deal with their general features. Fairbanks[3] has communicated a few notes on the diorites and gabbros in the province east of the north side of Lake Superior. Irving and Van Hise[4] have given a brief synopsis of the characteristics of the diabase dykes and interbedded sheets in the Penokee iron series on the south side

[1] A. C. Lawson: Notes on Some Diabase Dykes of the Rainy Lake Region. Proc. Can. Inst. for 1887, and Report on the Geology of the Rainy Lake Region. Pt. F., Ann. Rep. Geol. and Nat. Hist. Survey of Can. for 1887-88, pp. 57-73 and 147-164.

[2] G. H. Williams: The Greenstone Schist Areas of the Menominee and Marquette Region of Michigan. Bull. No. 62. U. S. Geol. Survey, 1890.

[3] H. W. Fairbanks: Notes on the Character of the Eruptive Rocks of the Lake Huron Region. Amer Geologist, I. 1890, p. 162.

[4] R. D. Irving and C. R. Van Hise: The Penokee Iron-bearing Series of Northern Wisconsin and Michigan. Monograph XIX., U. S. Geol. Survey, 1893. Chap. VII., The Eruptives.

of the lake, and of the gabbro, diabases, diorites, melaphyres and porphyrites of the Keweenawan overlying the Penokee series to the north, while Hall[1] has described a few hand specimens of diabases and gabbros from the Archæan of Central Wisconsin.

Further, in a discussion as to the nature of the diabase sheets interbedded with the Animikie slates and quartzites in Minnesota and Canada, which leads to the conclusion that the former are subsequent intrusions between the clastic beds, Lawson[2] gives a short generalized description of the petrographical characteristics of these rocks, and in a second article[3] he treats of the structure and composition of the anorthite rock of Irving, to which he gives the name anorthosyte. Finally, the writer in two articles refers to the coarse gabbro[4] of north-eastern Minnesota and to the peridotites and pyroxenites[5] associated with it along its northern border.

W. S. BAYLEY.

[1] C. W. HALL: Notes of a Geological Excursion into Central Wisconsin. Bull. Minn. Acad. Nat. Sciences, III., No. 2., p. 251.

[2] A. C. LAWSON: The Laccolitic Sills of the Northwest Coast of Lake Superior. Bull. No. 8, Geol. and Nat. Hist. Survey of Minnesota, p. 30.

[3] A. C. LAWSON: The Anorthosytes of the Minnesota Coast of Lake Superior Ib., p. 2.

[4] W. S. BAYLEY: A Fibrous Intergrowth of Augite and Plagioclase, resembling a Reaction-rim, in a Minnesota Gabbro. Amer. Jour. Science, XLIII. 1892, p. 515.

[5] W. S. BAYLEY: Notes on the Petrography and Geology of the Akeley Lake Region, in North-eastern Minnesota, 1892, p. 193.

A STUDY IN CONSANGUINITY OF ERUPTIVE ROCKS.

WITHOUT being distinctly formulated, the principle of consanguinity recently enunciated by Prof. Iddings has, as a working hypothesis, been the guide of studies made within the last few years on a group of Brazilian eruptive rocks, and the means of arriving at some interesting and, in part, novel results. The method of study followed, partly by plan, partly from force of circumstances, being the comparative study of a group of localities on the assumption of genetic relations between them, rather than detailed work at single points, was similar to what would be applied to the study of a sedimentary group. This method has in this case proved of great advantage, and, as a contribution to the subject of consanguinity, seems worthy of being put on record.

In 1883, the writer, whose previous training had been almost exclusively in the domains of palæontology and the distinctly sedimentary formations, finding himself in a region of crystalline and metamorphic rocks felt the need of acquainting himself with modern petrographic methods. Working in complete isolation without previous instruction in this branch, without material for comparison and almost without literature, he was also without the traditions of the science and preconceived ideas of the relations of the different petrographic groups, and thus free to follow out the lines of investigation suggested by their apparent field relations.

In working over the material at hand in the National Museum at Rio, attention was attracted to specimens of nepheline-syenite, or foyaite (using that term as a general title for the holocrystalline nepheline-orthoclase rocks) and as one of the localities, the peak of Tingua, was readily accessible from Rio an attempt to determine its field relations was resolved upon. This heavily wooded mountain proved a hard nut to crack, and several excursions gave very slender results beyond the fact that

with the predominant foyaite, phonolite and basaltic rocks, which have since been named monchiquites by Prof. Rosenbusch, occurred. These two last types, found only in loose blocks or in small dykes in gneiss that was clearly older than the foyaite, gave no idea of their relations to the latter rock except that at one point a small dyke of phonolite containing polyhedral inclusions of foyaite, like raisins in a pudding, was observed cutting foyaite of the same type as the inclusions. An examination of a series of railroad cuttings between the peak and the city showed a plexus of phonolite and monchiquite dykes together with a peculiar feldspathic rock of syenitic aspect, which, as they did not extend to the city, were suggestive of a possible genetic connection with the eruptive center of Tingua, or of some other similar center in the vicinity.

The occurrence of phonolites, hitherto only known on Brazilian soil on the volcanic island of Fernando de Noronha, suggested a search for phonolitic centers of eruption. About this time a chance collection made by a naval officer from the island of Cabo Frio, 60 miles from Rio, came to hand. As it contained specimens of both phonolite and foyaite, an excursion was resolved upon, guided by the thought that a rocky island on an open coast should give good exposures and thus perhaps prove a better point than Tingua for the study of the problems presented in this mountain. The island, from two to three miles long and from one-fourth to one-half mile wide, was found to give an almost continuous rock exposure about its entire margin. About four-fifths of the island is composed of coarse grained sodalite-bearing foyaite somewhat different from the Tingua type, and like it cut by numerous dykes of phonolite. The remainder consists of augite-syenite of two types, except a small point which is distinctly tuffaceous and cut by innumerable small dykes of a basaltic character. In one place dyke-like masses and large boulder-like inclusions of a pyroxene-plagioclase rock of a gabbro type occur. The coast of the mainland, distant half a mile more or less from the island, is entirely free from rocks of a syenitic character, and is composed of gneiss cut

by numerous dykes of phonolite, monchiquite and augite-syenite porphyry, as well as of diabase which, as it occurs everywhere in the gneiss regions of Brazil, was not taken into account. Although nothing definite on the field relations of these various rocks could be made out, the idea suggested at Tingua of a possible genetic relation between foyaite, phonolite and monchiquite was strengthened by this repetition of the association and mode of occurrence, that is to say, of a central mass of foyaite with apophyses of phonolite and monchiquite. Aside from this, the association of foyaite with augite-syenite, with a plagioclase rock and with tuff of a volcanic character, suggested other lines of investigation not in accord with the usually received notions regarding these rocks.

Before a second projected excursion to Cabo Frio could be realized a chance specimen of foyaite from the Poços de Caldas in southern Minas appeared at the Rio Museum. As a railroad was under construction in this region the idea at once presented itself that, aside from a study of this district, possibly Tingua and Cabo Frio might be studied more advantageously several hundred miles away than at those points themselves. Instead, therefore, of returning to Cabo Frio an excursion was made to Poços de Caldas where the expectations formed were more than realized. About twelve kilometers of almost continuous rock cutting up a steep mountain slope giving one of the finest and most varied exposures of eruptive rocks in the world, was found. Here immense masses of tuff are seen to be cut by both foyaite and phonolite ; dykes and sheets of foyaite pass into phonolite at their margins ; small masses of phonolite[1] are seen included in foyaite and *vice versa* masses of foyaite are included in phonolite. Considerable masses of a leucite rock, the first known from South America, cut by and buried under phonolite and presenting tuffaceous facies also occur. Small stringers of augite-syenite were noted in the tuffs and phonolite, and nests of

[1] The name phonolite is retained for these rocks since no petrographer, not knowing their association, would ever think of calling them anything else, although some, with that knowledge, prefer to call them nepheline-syenite porphyries or tinguaites.

decomposed crystals, at first taken for analcime, as well as polyhedral inclusions similar to those of the phonolite of Tingua were obtained. To complete the felicity of the excursion a cutting at the foot of the mountain showed the eruptive rocks to be in part, at least, contemporaneous with Carboniferous strata.

With the data here obtained a paper was prepared and presented to the Geological Society of London (Quart. Jour. 43, 1887) announcing the discovery and general distribution of nepheline and leucite rocks in Brazil, and the general conclusion that the Poços de Caldas eruptive center is volcanic in the most restricted sense of the term, that it is of Carboniferous age, and that here foyaite and phonolite occur as different phases of the same magma.[1]

The attack on Tingua was now renewed with the expectation that a diligent search would reveal something analogous to the Caldas region. A trip to the top of the peak showed little of interest beyond a dyke of phonolite cutting foyaite at the very summit. An examination of the margins, well shown by the cuttings of an extensive series of railroad and pipe lines (for the water supply of Rio) at the front, a river valley at the back and roads over the ridge at both ends of the peak, showed that the foyaite is limited to the massif and nowhere presents unequivocally the character of dykes. Two cuttings, one a tunnel, through a spur covered with foyaite boulders as if from the outcropping of a dyke, is conclusive on this point, as only gneiss was found *in situ*. The eruptive rocks are therefore placed like a plaster on the top and slopes of a gneiss ridge in a manner exceedingly suggestive of volcanic conditions. By forcing a way through the dense forest into the crater-like valley of a stream coming from the very heart of the mountain, the long-sought-for evidence of fragmental eruptives and of extensive masses of phonolite in

[1] Subsequent explorations of the Caldas center proves it to be one of the grandest volcanic masses of nepheline rocks known, measuring from fifteen to twenty miles in diameter. Contrary to the first impression the foyaite masses are comparatively insignificant, and the massif is composed essentially of phonolite and tuff with possibly a large proportion of basic leucite rock. A large and important mass of augite-syenite appears to form part of the same volcanic massif.

sheets rather than dykes was found. A complete analogy, as regards the essentially volcanic character of the massif, with the Caldas region was thus established with the addition of evidence of a lava-flow-like character in the foyaite masses. (Quart. Jour. XLVII., 1891).

A chance fracture of a Caldas specimen showing obscurely an appearance of dodecahedral faces on the external surface of the singular polyhedral inclusions so characteristic of the two places, suggested the search for partially decomposed material which by cleaving around the inclusions would show their true form and reveal the mystery of their origin. This search was rewarded with the discovery of free masses of foyaite, like those of Magnet Cove, Ark., having the external form of leucite. The presence of such rock masses with crystalline outlines in both phonolite and foyaite is another link in the chain of evidence of consanguinity of foyaite, phonolite and leucite rocks, while the presence of accessory plagioclase in some of these masses, taken in connection with the occurrence already noted at Cabro Frio, suggests another interesting line of investigation.

Meanwhile another series of studies presented in an unexpected manner certain new and interesting phases of the problem. Work had been commenced on a deposit of magnetic iron ore at Ipanema in the state of São Paulo where, from the extreme decomposition of the rocks and other unfavorable circumstances, but little could at first be made out beyond the association of the ore with a peculiar clay made up in large part of scales of hydrous mica. An ore of similar character at Jacupiranga in the same state was being investigated by Mr. Henry Bauer, a German mining engineer, and the collections sent by him showed the presence at that place of an undescribed type of holocrystalline nepheline-pyroxene rock since denominated jacupirangite,[1] which, by enrichment in iron, passes to an iron ore, and, by secondary alteration of the pyroxene, affords the same peculiar micaceous clay. Certain basic

[1] Am. Jour. of Science, XLI., 1891, p. 311. The same, or a very similar, type was described simultaneously from Finland by Ramsay and Berghell with the name of ijolith (Geologiska Föreningens i Stockholm Förhandlingar, No. 137, 1891).

eruptives in these collections suggested a comparison with the Tingua and Cabo Frio monchiquites, and Mr. Bauer was requested to search for the characteristic rocks of these places, specimens being sent him for comparison. The return mail brought typical specimens of foyaite, and with this indication of a new locality for that rock, and in the hope of being able to study the Ipanema ore deposit more advantageously at another place, an excursion to Jacupiranga was resolved upon. Under the guidance of Mr. Bauer, and aided by subsequent investigations by him and Dr. Eugen Hussak, the district was found to consist essentially of jacupirangite cut by dykes of foyaite with which is associated phonolite, various types of augite-syenite and a micaceous pyroxene-plagioclase rock in such a way that there is no escaping the conclusion of a genetic relation between these various types. Outlying dykes of the plagioclase rock assume in one place the characters of a gabbro, in another, those of a teschenite. Among the outlying dykes of the district are various types of basic eruptives, including leucite-basanite, vosgesite and syenite-porphyry whose relations to the eruptive center are less clear, but which are also suspected to be genetically connected with the nepheline-bearing types. Most interesting is a cryptocrystalline orthoclase-pyroxene rock passing to coarse grained augite-syenite and presenting a tuffaceous facies clearly indicative of volcanic action.

With the clues obtained at Jacupiranga the study of Ipanema became comparatively easy. The jacupirangite type passing to an iron ore was found as a dyke with the facies of a breccia at the margin, traversing decomposed rock which is evidently identical with the compact augite-syenite of Jacupiranga. By diligent search the latter was found in a sound condition and presenting a variety of interesting phases, such as a passage to coarse grained augite-syenite, tuffs identical with those of Jacupiranga and, most interesting of all, a basic facies in which the orthoclase is replaced by phosphate of lime in the form of apatite. A singular mode of occurrence, and one bearing directly on the question of consanguinity, is that of micro and macroscopic inclusions,

or segregations, of both the feldspathic and phosphatic types of augite-syenite in a phonolitic nephelinite, apparently without feldspar. The bulk of the iron ore at this place occurs as rounded nodular segregations associated with apatite in a decomposed rock which was evidently coarse grained and micaceous. This was evidently not jacupirangite, but apparently some peculiar type of nepheline or augite-syenite. Except for the absence of black garnets it apparently corresponds closely with the ore-bearing rock of Magnet Cove, Ark., described by the late Dr. J. F. Williams. It may be noted in this connection that the same character (absence of black garnet) distinguishes the jacupirangite from the ijolith of Ramsay and Berghell.

As in the Caldas region, there is at Ipanema evidence that the eruptive action took place in the late Carboniferous or post-Carboniferous times. This coincidence of age at two of the localities may perhaps justify the assumption (which cannot be directly proven for lack at the other places of sedimentaries intermediate between the very ancient and the very modern), that all of these eruptive centers are substantially contemporaneous. Bearing on this question of age, as also on that of consanguinity, is the fact that in a region characterized by Devonian and probably also Carboniferous strata in Paraguay, Pohlmann has reported nepheline-bearing basalt, and Dr. J. W. Evans has lately communicated specimens of foyaite and augite-syenite from Pão de Assucar on the Paraguay, proving that this mass, hitherto reputed to be granitic, represents another eruptive center similar to those studied in eastern Brazil.

The evidence of consanguinity of foyaite and phonolite consists of an intimate association within limited areas at all of the localities mentioned, except Ipanema, where neither type has as yet been found in a condition to be positively identified; of a direct passage to phonolite at the margins of foyaite masses at Caldas; of inclusions of phonolite in foyaite at the same place and conversely of inclusions, evidently formed *in situ* of foyaite in phonolite at Caldas and Tingua. In this connection may be mentioned an inclusion of the type of

foyaite, described by Prof. Rosenbusch and Dr. G. H. Williams from the phonolite massif of the island of Fernando de Noronha, whose eruption is presumed to be of much later date than that of the continental centers above described. Whatever may be the explanation of the assumption of the leucite form, without the substance of that mineral, by these inclusions at Caldas and Tingua, this phenomenon may also be cited as an evidence of consanguinity. Confirmatory evidence is afforded by the intimate association of typical leucite and nepheline rocks in the Caldas massif, and perhaps also by the occurrence in Paraguay.

The evidence of consanguinity of the augite-syenite type with those bearing nepheline is almost equally complete. At Tingua, where there is an apparent lack of this type, a single large fragment was found as an inclusion in foyaite. At Jacupiranga, a direct passage by disappearance of nepheline, from foyaite to one phase of augite-syenite could be traced, while other phases of the same type were found associated with foyaite in the same dyke or boss. Most interesting is the association of this type at Jacupiranga and Ipanema with nepheline rocks more basic than the foyaites and phonolites, such as the jacupirangites and phonolitic nephelinites, in the latter of which it occurs as an inclusion or segregation. In this connection it is interesting to note the tendency, rare among the orthoclase rocks, of this type to present olivine as an accessory element.

Still more interesting, though less conclusive, are the indications of consanguinity of foyaite with a group of plagioclase rocks hardly, if at all, distinguishable from those of entirely different genetic relations. At Cabo Frio the appearance is certainly that of segregations of a plagioclase rock in the midst of foyaite, though farther investigation is desirable. At Jacupiranga the two types not only occur in the same dyke or boss, but nepheline has actually been observed as a rare accessory in the gabbro-like rock. The appearance of plagioclase in the pseudo-leucite crystals of Tingua bears on the same question, as does also the appearance in a large collection of phonolite from Fernando de Noronha of a single specimen of an andesite-like rock, which unfortunately

was not observed in time to be included in the material sent to Dr. G. H. Williams for study. Apparently there is a group of gabbro and diabase-like rocks whose genetic relations are with the nepheline-bearing rocks rather than with the ordinary members of the groups which they so closely resemble.

The peculiar and varied group of basic dyke rocks recently denominated monchiquites by Prof. Rosenbusch, afford evidences of consanguinity by their almost constant association, as apophyses, with the nepheline-bearing eruptive centers to whose immediate vicinity they appear to be limited. If certain decomposed dykes at Caldas and Ipanema are correctly referred, this group occurs at all the Brazilian localities. A single instance of a basic segregration resembling this type has been observed in a dyke of phonolite. The occurrence within the space of a few meters in the Tingua phonolitic tuffs of three small dykes of this type, of which two, standing alone, would be taken as representing tephrite and limburgite is suggestive of another line of consanguinity. Equally suggestive is the occurrence of vosgesite in the vicinity of the Jacupiranga center of eruption.

Finally the evidence of volcanic action in the presence of fragmental eruptives found at all of the five localities in constant association with types ordinarily regarded as plutonic, such as augite-syenite, is exceedingly suggestive.

ORVILLE A. DERBY.

SÃO PAULO, BRAZIL, Aug. 1, 1893.

THE DISSECTED VOLCANO OF CRANDALL BASIN, WYOMING.*

THE writer in exploring the north-eastern corner of the Yellowstone National Park and the country east of it came upon evidences of a great volcano, which had been eroded in such a manner as to expose the geological structure of its basal portion.

The work was carried on as a part of the survey of this region, under the charge of Mr. Arnold Hague of the U. S. Geological Survey. The paper is an extract from a chapter in the final report on the Yellowstone National Park in process of completion, and the writer is indebted to Major J. W. Powell, Director of the Survey, and to Mr. Hague, chief of the division, for permission to present it at this time in anticipation of the publication of the final report.

The area of volcanic rocks described is but a small portion of the great belt of igneous material that forms the mountains of the Absaroka range, lying along the eastern margin of the Yellowstone Park.

The volcano of Crandall Basin is one of a chain of volcanic centers situated along the northern and eastern border of the Yellowstone Park, which are all distinguished by a greater or less development of radiating dikes, and by a crystalline core eroded to a variable extent.

The Palæozoic and Mesozoic strata, which formed an almost continuous series to the coal-bearing Laramie, had been greatly disturbed and almost completely eroded in places before the volcanic ejectamenta in this vicinity were thrown upon them. The period of their eruption is, therefore, post-Laramie, presumably early Tertiary.

The first eruptions of andesite were followed by those of basalt in great amounts, and these by others of andesite and

*Abstract of a paper read before the British Association for the Advancement of Science, September, 1893.

basalt like the first. This was succeeded by a period of extensive erosion; reducing the country to nearly its present form. Then came the eruption of a vast flood of rhyolite constituting the Park plateau, which was followed in this region by smaller outbreaks of basalt. The last phase of volcanic activity is found in the geysers and fumaroles which have rendered this region famous.

The volcano of Crandall Basin consists chiefly of the first series of basic andesites and basalts. The earlier acidic andesite, which occurs beneath these rocks, appears to be the remnants of eruptions from neighboring centers.

Nothing remains of the original outline of the volcano. The district is now covered by systems of valleys and ridges of mountain peaks that rise from two thousand to five thousand feet above the valley bottoms. The geological structure of the country, however, makes its original character evident.

The outlying portions of the district to the south, west, and north consist of nearly horizontally bedded tuffs, and subaërial breccias of basic andesite and basalt. With these are intercalated some massive lava flows, which are scarce in the lower parts of the breccia, but predominate in the highest parts, above an altitude of ten thousand feet. Here they constitute the summits of the highest peaks.

In contrast to the well-bedded breccias around the margin of the district, the central portion consists of chaotic and orderless accumulations of scoriaceous breccia with some massive flows. These breccias carry larger fragments of rocks and exhibit greater uniformity in petrographical character.

A still more noticeable feature of the central portion of the district is the occurrence of dikes which form prominent walls, and may be traced for long distances across the country. The greater part of them are found to converge toward a center in the highest ridge in the middle of the drainage basin of Crandall creek. A small number converge toward a second center three or four miles east of the first. In the southern part of the district there are many dikes trending toward a center near the

head of Sunlight Basin, about fifteen miles south of the Crandall center.

The center toward which the Crandall dikes converge is a large body of granular gabbro, grading into diorite. It is about a mile wide, and consists of numerous intrusions penetrating one another and extending out into the surrounding breccia, which is highly indurated and metamorphosed in the immediate vicinity of the core. Within the area of indurated breccia the dike rocks become coarse grained rapidly as they approach the gabbro core. This was undoubtedly the central conduit of an ancient volcano, the upper portion of which has been eroded away.

Upon comparing the geological structure of this region with that of an active volcano, like Etna, it is apparent that the lava flows which form the summits of the outlying peaks must have been derived from lateral cones fed by dikes radiating from the central conduit. And assuming that the volcano of Crandall Basin was similar in type to that of Etna, an idea of its original proportions is derived by constructing upon profile sections through the Crandall cone the outline of Etna. If the erosion of the summits of the highest peaks is neglected, the resulting height of the ancient volcano above the limestone floor is estimated at about thirteen thousand four hundred feet. This is undoubtedly too low, and is well within the limits of present active volcanoes. Erosion has removed at least ten thousand feet from the summit of the mountain to the top of the high central ridge in which the granular core is situated, and has cut four thousand feet deeper into the valleys on either side. It has prepared for study a dissected volcano, which, it is hoped, will in time reveal some of the obscurer relationships existing between various phases of igneous rocks.

Petrological Features.—It will not be possible in an abstract to do more than present, in the briefest manner, the more salient features of the petrology of the rocks of this volcano. The rocks are mostly the same as those in various parts of the Yellowstone National Park, some of which have been described in another place. The older acidic breccia consists of fragments

and dust of hornblende-mica-andesite, hornblende-andesite, and hornblende-pyroxene-andesite. They are partly glassy and partly holocrystalline. In some places they appear to pass into the overlying breccia, but in others they have been eroded and weathered before the latter were thrown over them.

The upper breccia, which constitutes the main mass of the volcano, is basaltic as a whole. It consists of pyroxene-andesite and basalt, the latter predominating in the upper part of the accumulation. The massive flows, as far as investigated, are all basalt. The composition varies constantly within narrow limits. A greater part of these rocks contain glassy groundmass.

The rocks constituting the dikes exhibit more variation than the breccias, though the majority of them are like the breccias in composition and habit, being basalt. They are generally more crystalline. A great many dike rocks resemble the basalts in outward appearance, but have little or no olivine, and are more crystalline. The absence of olivine from the more crystalline forms of these rocks appears to be due to the conditions which influenced the crystallization of the rocks and not to their chemical composition. For in some cases what appear in hand specimens to be decomposed olivines are found to be paramorphs after this mineral, consisting of grains of augite, magnetite, and biotite. As the rocks become more crystalline biotite becomes an essential constituent; the porphyritical minerals lose their sharpness of outline and assume some of the microscopical characteristics which they possess in gabbro.

Within the core the coarest grained forms are gabbro. The composition varies in different parts of one continuous rock mass, and also between different intrusions within the core. The transition is from gabbro to diorite with biotite and quartz; and the extreme variety is that form of granite called aplite; the range in silica being from 51.81 to 71.62 per cent.

Fine grained, andesitic equivalents of diorite occur in dikes outside of the core, but none of the most silicious varieties have been found outside of it. From this it appears that toward the end of volcanic activity near the core the composition of the

magmas became more and more silicious, and the volume of the lava erupted smaller. But this change in composition was not uninterrupted, for there are evidences of the alternate eruption of basic magmas as well. Dikes of more silicious rocks are traversed by later dikes of basic rocks. This has taken place both within and outside of the core. Some of these basic rocks are uncommonly low in silica for rocks of this region. They are all found at some distance from the core, with one exception, which is an intrusion within the core. They are lamprophyric in the sense used by Professor Rosenbusch, and approach more or less closely typical camptonites, monchiquites, kersantites, and minettes. They are connected with the basalts of the district by mineralogical and structural transitions.

These exceptionally basic rocks are the chemical complements of the acidic ones in the core and appear to be among the latest extrusions. While they agree with one another in having a low percentage of silica, they differ in the relative abundance of magnesia, lime and iron oxide on the one hand, and of alumina, soda and potash on the other.

As already pointed out by the writer in another place, the variability in composition of all of the volcanic rocks in this volcano illustrates one mode of differentiation of a magma at a particular center of eruption. A comparison of the chemical and mineral composition of the rocks of this district furnishes additinal evidence of the fact that magmas which are chemically similar will crystallize into different groups of minerals according to the conditions through which they pass. Thus chemically similar magmas may form basalt under one set of conditions, and gabbro under others; the first composed of plagioclase, augite, olivine, magnetite and sometimes hypersthene; the second consisting of plagioclase, augite, hypersthene and biotite, besides some magnetite, orthoclase and quartz, with or without hornblende.

Minerals, then, which are primarily functions of the chemical composition of rocks are also functions of the physical conditions affecting crystallization. Some of the conditions under which the molten magmas solidified within the dikes and core of the

volcano of Crandall basin, may be inferred from a consideration of the geological structure of this ancient volcano. The magmas which solidified within that portion of the core now exposed, and those in dikes within a radius of two miles, must have occupied positions at nearly the same distance beneath the surface of the volcano, that is, at a depth of about 10,000 feet and over. The one was as deep-seated or abysmal as the other, and yet their degrees of crystallization range from glassy to coarsely granular.

The influence of pressure on the crystallization is not recognizable either in the size of grain or the phase of crystallization. Marked changes in the crystallization may be traced horizontally in the immediate vicinity of the core. They are rapid near the core, and are accompanied by the induration and metamorphism of the surrounding rocks. They are in a general measure independent of the size of the rock-body, since narrow dikes within the core are coasely crystalline, while much broader ones in the surrounding breccias are very fine grained. It was, unquestionably, the differences in the temperature of the core rocks and of the outlying breccias which affected the degree of crystallization. The former must have been more highly heated than the latter rocks, and the magmas solidifying within them cooled much slower than those injected into the outlying parts of the volcano. In this case the depth at which the magmas solidified appears to have been of little moment in comparison with the temperature of the rocks by which they were surrounded.

The core of gabbro and diorite with an intricate system of veins of middle grained porphyritic rocks, and radiating dikes of aphanitic and glassy lavas, encased in an accumulation of tuffs and breccias with flows of massive lava, constitute an extinct or completed volcano. The central core consists of the magmas that closed the conduit through which many of the eruptions had reached the surface. In solidifying they became coarse grained. The question naturally suggests itself, Are these coarse grained rocks any less volcanic than those that reached the surface? What part of a volcano is non-volcanic?

JOSEPH P. IDDINGS.

NOTES ON THE LEAD AND ZINC DEPOSITS OF THE MISSISSIPPI VALLEY AND THE ORIGIN OF THE ORES.

THE recent closing down of the silver mines of Colorado and other Western states means not only a lessening of the silver production of the country, but also the shutting off of its greatest source of lead supply. During the past few years over two-thirds of the total yield of domestic lead has been from the argentiferous lead ores of Colorado, Utah, Idaho, Montana and Nevada. Unless operations are resumed in the West, the demand must consequently soon be concentrated upon the deposits of non-argentiferous lead in the Mississippi Valley, which have been in the past the sole important producers. A rise in the price of lead is to be expected as a result, which, in turn, will lead to increase in exploitation and development.

The question naturally arises, therefore, to what extent are these Mississippi Valley deposits to be depended upon for future supply. They have been large and almost constant producers in the past; will they continue to be such in the future? The history of their development, which is in many respects remarkable, lends color to the hope that such will be the case, especially in Missouri. Lead mining was begun in that state as much as 170 years ago, and has continued almost uninterruptedly since. Indeed, the first deposit worked, that of Mine La Motte, has up to this year supplied large quantities of ore, the total value of its product to date being in the neighborhood of $8,000,000. The various bodies of ore have shown signs of exhaustion from time to time, and the industry in the state has waned. About the year 1854 the condition was such that even so competent a judge as Prof. J. D. Whitney[1] ventured the prediction that the supply was nearly exhausted, and that the lead mining of Missouri was a thing of the past. But ever after such depression, deeper excavations have developed new bodies of untouched ores, wider explo-

[1] Metallic wealth of the United States, p. 419.

rations have revealed new fields, or improvements in mining and metallurgical methods have made previously rejected ores available. Along with this, the utilization of the associated zinc ores has led to the opening up of deposits which previously lay untouched, enclosing often unexpected quantities of lead. During the past twenty years Missouri's production has reached large proportions. The total amount mined during this period is fully twice that of the preceding 150 years—a startling refutation of the early adverse predictions. The output during recent years has been only second to Colorado's, and this year will probably be first among the states of the Union; the total amount produced to date probably equals, if it does not exceed, that of any other state.

Similar in some respects are the facts of zinc production. The mining of these ores does not, however, date much more than twenty years back, and hence the industry has not suffered much from the vicissitudes of the early mining. The production grew rapidly from its beginning, and now ranks first in the country. The total output up to the present time is nearly equal to the combined total productions to date of all other states in the Union.

The showing for the Upper Mississippi or Wisconsin zinc and lead area is not quite so good. Mining there dates hardly more than 100 years back, and it was not on an active basis before 1823. The period of maximum work was about the year 1845, and soon after this time Prof. Whitney seems to have been of the opinion that its prospects were better than Missouri's, though he predicted a continued decline. The utilization of the zinc ores began about 1860, which tended to sustain the mining industry and the production of lead, though on a much reduced scale. In the early seventies the production of zinc was quite large and something like a resuscitation of mining took place. During the past thirteen years there has, however, been a general decline, and recently little mining has been in progress. At the time of maximum activity, in 1845, the production of lead was about 27,000 tons per annum; but that of zinc ore, in 1872, was only 22,000 tons. The total amount of lead produced to date is prob-

ably something over 650,000 tons, and of zinc ore only about 250,000 tons.

With such facts in mind it is of interest to note that the deposits to which they relate are the subjects of renewed study at the present time, and the prospect of increased demands upon them, above referred to, makes the revival of the discussions of their origin and mode of deposition most timely.

At the recent meeting of the American Institute of Mining Engineers, held as part of the International Engineering Congress, three papers were presented bearing, in whole or in part, upon the ores of the Mississippi Valley, and another, on the Bertha zinc mine of Virginia, described an ore body belonging essentially to the same class. These papers were by Messrs. F. Posepny[1], W. P. Jenney[2], S. F. Emmons[3], W. P. Blake[4], and W. H. Case[5], respectively.

The first of these papers, by Professor Posepny, is a description and discussion of ore deposits in general, in which he advocates their deep-seated origin through the medium of hot solutions derived from great depths. The second paper, by Dr. Jenney, is an exposition of his views concerning the origin of the Mississippi Valley ores, derived from his recent studies in the region. He repudiates the explanation of lateral concentration advocated by Whitney and Chamberlin, and reverts to the old ideas of Owen and Percival, that the ores have come from below, thus harmonizing with Posepny. The other three papers are principally descriptive, though Mr. Emmons quotes Dr. Jenney's conclusions as applied to the Mississippi Valley ores.

Posepny's direct reference to the ores here discussed is brief. He marshals few facts from the region itself in support of his theory, but rather argues, in a negative way, that no great obstacles exist there which would prevent its accceptance. Thus,

[1] The Genesis of Ore Deposits.

[2] The Lead and Zinc Deposits of the Mississippi Valley.

[3] Geological Distribution of the Useful Metals in the United States.

[4] The Mineral Deposits of Southwest Wisconsin.

[5] The Bertha Zinc Mine.

as positive evidence in Missouri, he states that while the deposits away from the granite and porphyry "islands" of southeastern Missouri consist chiefly of lead and zinc ores, "other metals, such as copper, cobalt and nickel occur as the Archean foundation rocks are approached." This circumstance, he states, is "an indication that the source of the lead deposits also is to be sought in depth." Whatever may be the value of this "indication," the facts, as stated, do not hold generally, in the opinion of the writer. Professor Posepny reasons, presumably, from observations made at Mine La Motte, where such conditions exist. At other places, however, these changes in composition are not observed as the crystalline rocks are approached. At Bonne Terre copper pyrite was found in the old *upper* workings containing about four per cent. of nickel and cobalt. It does not characterize the deeper ores. At Doe Run, a mine recently opened, work is prosecuted along the old water-worn pre-Cambrian surface of the Archean granites, amid the very conglomerate boulders, and very little copper pyrite with cobalt and nickel is found. Again, at other localities in St. Genevieve, Franklin, Crawford and other counties, copper ores occur remote from any granite or porphyry outcrops, and well above the basal beds of the Cambrian.

In the way of negative evidence, our author, in considering the Wisconsin deposits, seems to think the absence of ores in the great thicknesses of limestones and sandstones which underlie the productive horizons a by no means conclusive fact as opposed to their deep-seated source, and suggests that the solution may have come up through a passage not yet exposed, and even that fault fissures and eruptive dikes exist which have not been discovered. From the fact that he refers in this connection only to Whitney's report of 1862, we conclude that he has not had access to the later and more exhaustive works of Strong and Chamberlin. Perhaps, with the full light conveyed by these reports and accompanying maps, Professor Posepny might have attached more importance to the objections raised. It is difficult to conceive how such a passage for the solutions as he suggests

could possibly exist without its presence having been revealed and its course traced, with all the widespread mining and exploring which has been conducted in this region during the past seventy years. Neither can one see how the solutions could traverse the intervening great thicknesses of water-soaked sandstone without becoming diffused, in great part at least. The failure to find such a passage and the absence of the ores in the beds assumed to have been traversed, though evidence of a negative character is so strong that it becomes of almost positive value in support of the theory of lateral segregation.

Dr. Jenney, in support of his position, recognizes systems of fault fissures in the ore districts of both south-western and south-eastern Missouri, which cross each other in different directions; these, he considers, served as channels for the metal bearing solutions, and the association of the fissures with the ore bodies he adduces as evidence of such derivation. The deposits of the south-western portion of the state occur almost exclusively in the Mississippian or Lower Carboniferous limestone. Cross fissures or fault fissures in the rocks, if they exist, are not very apparent. The strata are undoubtedly very much shattered in certain limited areas, and have been subjected to extensive subterranean erosion and corrosion and great silicification. Of a system of extensive or considerable faults, recent stratigraphic work in this region has, however, revealed nothing.

In the Cambrian limestones of the eastern part of the state the conditions are somewhat different. Crevices and fissures are there plainly developed, and evidence of considerable faulting is indubitable. In Franklin County such vertical crevices have supplied large quantities of ore. In that portion of the southeast to which reference is especially made, however, and which has produced by far the bulk of the lead, the crevices, whether marking faults or not, are of insignificant dimensions, and the experience has been that they contained themselves little or no ore. On the contrary, the great ore masses consist of galena disseminated through a thickness of the country rock, often of fifty feet or more. At Bonne Terre a tract 1300 feet long by 800

feet wide has been mined out of such diffused ore. The crevices which traverse this ore body are frequently almost blind, and can only be detected by the drip of roof water. These are such as occur in almost any massive rock. Further, one of the most important faults in this region, which traverses the country about two miles north of Mine La Motte, with an apparent throw of 300 feet, is entirely unaccompanied by ore, though the adjacent ground has been prospected with the diamond drill. Again, not a single instance can be recalled by the writer, in those mines which work to the very contact with the underlying granite, where faulting crevices extend down into that rock. They possibly do so extend in some instances, but there is no positive evidence adduceable that they then continue ore bearing. Apart from this, however, the association of ore and crevices, of course, does not denote by any means a deep-seated source for the ore. Such crevices generally act both as channels controlling their distribution, and as receptacles for their accumulation whatever the source of the ores. Hence, a disturbed and creviced region, which is in other respects adapted to the reception of ores, will be their most natural habitat. Therefore the explanation of the localization of the deposits based upon such conditions is equally consistent with any of the common theories of ore derivation. The same, it would seem, can be said concerning the observed paragenesis of the minerals and the growth of crystals, in which Dr. Jenney sees additional foundation for his conclusions. If we accept the broader idea of lateral secretion, which does not demand that a mineral shall be derived from the very rock to which it is attached, but recognizes abundant flow along crevices and through porous strata and a consequent free transfer of solutions from place to place, all the phenomena find at least an equally ready explanation. It is argued further, in this paper, as against the lateral secretion theory, that the metallic contents of the country rocks are insufficient to have supplied the ore bodies. The grounds for this statement are only suggested; but, to the best of our knowledge, the fact yet remains to be proven. Due allowance is not made for the many and various ways in

which minute quantities of substances disseminated through vast volumes of rock may be brought together.

In evidence of the post-Carboniferous age of the deposits the statement occurs several times in Dr. Jenney's paper, that the ores occur in the Coal Measures. This, we think, should be made with limitations. They are found in shales of that age in Jasper county, and at a few other localities, but these shales are in isolated patches, which occupy depressions in the older ore-bearing Mississippian rocks. The metallic contents of the coal may, hence, be derived, by some secondary process of transfer, from adjacent ore bodies. In any case, the Coal Measures in the state, as a whole, are practically destitute of these ores, and they can thus hardly be stated to occur in that formation, whether their absence be due to their prior formation or to limitations in their distribution determined by physical causes.

Dr. Jenney seeks further to find support for the hypothesis of the deep-seated origin of the ores through analogy, in stratigraphy and geologic history, with regions of the far West. This attempt does not seem, in our judgment, to be successful. The last pronounced regional disturbance of both the Ouachita and Ozark uplifts was immediately after the Coal Measure period. In Arkansas this was accompanied by great flexing of the strata. There is no evidence in the Ozark uplift of any intense disturbance of post-Cretaceous date, or of the presence, even at great depths, of flows of such igneous rocks as accompanied the uplift and preceded the ore formation of the Rocky Mountains. As already expressed, the Missouri ores cannot be properly considered to occur in the Coal Measures of the state. Did such a profound fissuring take place in post-Cretaceous times as Dr. Jenney's hypothesis requires, we should expect to find it extending into the body of the Coal Measures, accompanied by the ores. At least faulting or other such exhibition of disturbance would be found, which phenomena do not characterize these rocks.

Over and above these considerations affecting the quality of the support of this theory, there still remain the positive obstacles to be disposed of. The almost entire absence of the

precious metals in the Missouri ores is a fact which further weakens the force of any analogy which may exist between their conditions of deposition and those of the Rocky Mountain ores. How are the objections raised by Whitney and Chamberlin, discussed in a previous paragraph, to be met; such as the facts that faults are practically absent from the region; that there is little ore in the underlying Lower Magnesian beds and none in the Potsdam and St. Peter's sandstones; that no deep and continuous crevices like true fissures are found; that no hydrostatic cause is assigned for the ascension of the solutions from great depths. How could the ores be carried across such thick pervious and water-soaked strata as those of the Potsdam and St. Peter's formations?

The generally accepted facts that the deeper-seated rocks are richer in metallic constituents; that subterranean waters are of high temperature and under great pressure, and consequently are powerful solvents; that the relief of pressure and the diminution of temperature accompanying the ascent of such solutions supply an abundant cause for the deposition of their metallic burdens, are all good and enticing general reasons in favor of the adoption of the theory of a deep source for *all* of our metalliferous deposits. Yet, on the other hand, we must recognize that *some* of our ores, notably those of iron and manganese, cannot be assigned such an origin. Why is it not possible, on general grounds, that other ores should be gathered as are those of these two metals? In reply, it is manifest that we cannot rely entirely upon such general principles, as they are at present understood; but must resort to specific facts in connection with special cases. Few definite facts relating to this Mississippian area have been adduced in these recent papers which can stand as new reasons for believing in the deep origin of the ores, an explanation long since offered by Owen and Percival. Neither have we attempted to introduce positive demonstration in opposition to it. The question seems to be very much *in statu quo*, and, so long as it so remains, the old objections hold good and must be done away with before a change of opinion is warrantable.

ARTHUR WINSLOW.

EDITORIAL.

THE Lake Superior excursion, under the leadership of Professors Van Hise and Wadsworth, which preceded the scientific meetings at Madison and Chicago, was participated in by a goodly company of foreign and American geologists from whose testimony we learn that it was unusually profitable and enjoyable. It was thoroughly planned, even to minor details, and carried into execution with remarkable precision, no time being wasted by errors or by undue attention to trivial features. Brief lucid explanations by the guides brought out the essential features of the formations and greatly facilitated observation.

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THE meeting of the Geological Society of America at Madison was attended by somewhat larger numbers than usually gather at a summer meeting. The following twenty papers were offered and read in full or given in substance, with the exception of two, whose authors were absent, and which were only read by title for lack of time: On the Study of Fossil Plants, by Sir J. Wm. Dawson ; On a New Species of *Dinichthys*, On a new *Cladodus* from the Cleveland Shale, and On a Remarkable Fossil Jaw from the Cleveland Shale, by E. W. Claypole; Origin of Pennsylvania Anthracite, by J. J. Stevenson; The Magnesian Series of the North-western States, by C. W. Hall and F. W. Sardeson; On the Succession in the Marquette Iron District of Michigan, by C. R. Van Hise; Extra-morainic Drift in New Jersey, by G. Frederick Wright; On the Limits of the Glaciated Area in New Jersey, by A. A. Wright; South Mountain Glaciation, by Edward H. Williams, Jr.; Terrestrial Subsidence South-east of the American Continent, by J. W. Spencer; Evidences of the Derivation of Kames, Eskers, and Moraines of the North American Ice-sheet, chiefly from its Englacial Drift, and The Succession of Pleistocene Formations in the Mississippi and Nelson River Basins, by Warren Upham ; The Cenozoic History of Eastern Vir-

ginia and Maryland, by N. H. Darton; Notes on the Geological Exhibits of the World's Fair, by G. H. Williams; Dislocation of the Strata of the Lead and Zinc Region of Wisconsin and their Relation to the Mineral Deposits, with some observations upon the Origin of the Ores, by W. P. Blake; Geology of the Sandhill Region in the Carolinas, by J. A. Holmes; The Gravels of the Glacier Bay in Alaska, by H. F. Reid; The Arkansas Coal Measures in their Relation to the Pacific Carboniferous Province, by James Perrin Smith; Glaciation of the White Mountains, N. H., by C. H. Hitchcock.

Professor Reid's paper on the Gravels of Glacier Bay was given the form of an illustrated evening lecture, and was found entertaining and instructive by the popular audience as well as the members of the society. By admirable photographic illustrations he brought forth very clearly and impressively many of the features of glacial action. It was peculiarly valuable as illustrating the behavior of alpine glaciers when they reach unusual magnitude, and particularly when they approach the Piedmont type.

The paper of Sir J. Wm. Dawson does not admit of ready synopsis. It needs to be read in full. Professor Claypole presented a number of interesting and apparently important facts relative to fossil fishes from north-eastern Ohio.

One of the more notable papers was that of Professor Stevenson, in which objections were urged against the current doctrine of the origin of anthracite through metamorphic agencies connected with heat and pressure. In lieu of this hypothesis, which the author held to be untenable, an hypothesis was offered connecting the origin of anthracite with the conditions of deposition. Anything less than a full statement of the author's view in his own language would fail to do it justice.

The paper of Professor Hall and Mr. Sardeson, read by the latter, endeavored to correlate, in much detail, the series of magnesian limestones of the north-western states. The most notable feature was the placing of the dividing horizon between the middle and the upper Cambrian considerably higher than has been done by most previous writers, throwing the larger part of the

light-colored sandstones that lie below the alternating series into the middle rather than the upper division.

Professor Van Hise gave a lucid sketch of the succession of deposits in the Marquette district and the grounds on which his interpretation is based. The paper showed the steady progress that is being made in the disentanglement of the gnarled structure of that region.

The papers of the Professors Wright awakened special interest from their relation to previously controverted ground. Contrary to their recent contention, they now extend the glaciated area so as to include the localities of High Bridge and Pattenburg and a considerable territory in the Triasic region essentially as maintained by Professor Salisbury before the Professors Wright took up the special study of the matter, though this was not as distinctly acknowledged as might have been desired. The discussion on the part of Chamberlin and McGee took the congratulatory form in view of the removal of one important point of difference and the advance toward harmonious views. It was noted that the points of difference were essentially reduced to two: The correlation of the Trenton gravels and the age of the extra-morainic drift relative to the moraine. In regard to this last it was pointed out that an important contribution had been made, unwittingly perhaps, to the presumption of great difference in the ages of the two drifts, in the fact that the outer drift, especially at such localities as High Bridge and Pattenburg, where it is thick, could not be presumed to be of the same age and character as that of the moraine and moraine-bordered drift, or its glacial origin would not have been previously denied by the Messrs. Wright, and that its age must be presumed to be very much greater or it could not have been referred to a residuary origin, especially to residuary derivation from formations which have disappeared from the neighborhood, since the moraine and moraine-bordered till are very distinctly characterized glacial formations of fresh aspect, while residuary accumulations and residuary topography are inherently expressions of age.

Dr. Spencer submitted a large mass of valuable data relative

to submerged channels in the south-eastern part of the continent, particularly the Antillean region, and urged these as evidences of very great subsidence. The paper awakened considerable discussion, the general tenor of which was the acceptance of the evidence and of the inference of subsidence, with an expression of doubt as to the time of its occurrence and its relations to other geological events.

The paper of Mr. Upham was a fuller statement of the arguments he has recently advanced in support of the derivation of kames, eskers, and moraines chiefly from englacial drift. These, and his views of the internal movement of the ice upon which they are in some degree founded, were opposed by Reid on physical grounds and by others on observational grounds. It was remarked that existing glaciers fail to show basally-rubbed material on their surfaces, even on their low terminal slopes, at least as a common fact. In his second paper, Mr. Upham urged a somewhat simple and brief succession of Pleistocene formations. The successive lines of moraines and the observed overlaps of till were interpreted as signifying minor and relatively brief halts and readvances of the ice. In the discussion, this position was opposed as being inconsonant with the evidences of interglacial intervals and of intervening erosions, oxidations and other changes which the formations were thought to present.

The papers of Darton and Holmes on different but analogous portions of the coastal region showed the very great advances which have been made in the last few years in the analysis and differentiation of the coastal formations, and the interesting discussions they called forth showed, in some measure, the important bearing these have upon the interpretation of the Pleistocene and immediately Pre-Pleistocene histories of the glaciated region.

Professor W. P. Blake, while coinciding in general in the views held by Whitney and by Chamberlin respecting lead and zinc deposits, urged the existence of a greater amount of dislocation than they had recognized, and attributed to it greater influence in the localization of the deposits. His views are intermediate

between those of the authors mentioned and those recently advanced by Mr. Jenney.

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THE attendance upon the meeting of the American Association was less than usual, but the interest and the character of the papers compared favorably with those of other sessions. The provisions made by the local committee were excellent, and the hospitalities extended by the citizens of Madison were graceful and generous. The exceptional beauties of the place and the superb weather lent attractiveness to the occasion.

In the Geological Section, the following papers were offered, and, with few exceptions, read in full or in substance: Gravels of Glacier Bay, Alaska, with lantern illustrations, by H. F. Reid; Use of the Name "Catskill," by John J. Stevenson; Section across the Coastal Plain Region in Southern North Carolina, by J. A. Holmes; Notes on Further Observations of Temperature in the Deep Well at Wheeling, W. Va., by William Hallock; Recent Investigations in the Cretaceous Formation on Long Island, N. Y., by Arthur Hollick; Character of Folds in the Marquette Iron District, by C. R. Van Hise; The Fossil Sharks of Ohio, by E. W. Claypole; Hillsdale County Geology, by Horatio P. Parmelee; Exhibition of Trilobites, showing Antennæ and Legs, by Chas. D. Walcott; Remarks on the genus *arthrophycus* Hall, On the Value of Pseudo-algæ as Geological Guides, Studies in Problematic Organisms, and The Genus *Fucoides*, by Joseph F. James; Northward Extension of the Yellow Gravel in New Jersey, Staten Island, Long Island and Eastward, by Arthur Hollick; Some Questions Respecting Glacial Phenomena about Madison, by T. C. Chamberlin; Amount of Glacial Erosion in the Finger Lake Region of New York, by D. F. Lincoln; Ice-sheet on Newtonville Sandplain, by F. P. Gulliver; Additional Facts Bearing on the Question of the Unity of the Glacial Period, by G. Frederick Wright; Changes of Drainage in Rock River Basin in Illinois, by Frank Leverett; Graphic Comparison of post-Columbia and post-Lafayette Erosion, by W J McGee; An Illustration of the Effect of Stagnant Ice in Sussex Co., N. J., and A Phase of Superficial Drift, by R. D. Salisbury;

Tertiary and Quarternary Stream Erosion of North America, by Warren Upham; The Emergence of Springs, by T. C. Hopkins.

As the writer was unable to hear a considerable number of these papers his notes must be confined to comparatively few of them. The paper of Mr. Lincoln presented a very interesting sketch of the quite remarkable evidences of glacial erosion and modification of surface in the Finger Lake region of New York. He showed, successfully we think, that the existing topography could not have arisen in its present form through the agency of subaërial degradation alone nor by the simple deposit of drift material on a surface so produced, but that a very notable amount of reshaping of the rock-surface was the result of glacial abrasion.

Mr. Frank Leverett made a quite important contribution to the data bearing upon the stages and duration of the earlier glacial epoch. He has recently discovered evidence that the Rock River formerly flowed nearly due south from a point near Rockford into the Green River basin, and presumably onward to the great bend of the Illinois River, near Hennepin, where an old deep channel exists. From this course the river was diverted to its present south-westerly course by the earliest or at least one of the earlier stages of the ice invasion of that region. Between the time of this diversion and the stage at which the kettle moraine was formed across the Rock River about forty miles to the north, near Janesville, Wis., the river cut a trench in rock across a succession of preglacial cols to maximum depths estimated at 100 to 125 feet. Mr. Leverett made careful estimates of the total amount of rock excavation and found it to amount to one square mile 1100 feet deep. Stated in another form, this equals a trench 100 feet deep, one mile wide and eleven miles long, or one-half mile wide and twenty-two miles long. After the trench had been cut, the glacial wash from the outer edge of the kettle moraine partially filled the trench as shown by remnants of terraces still existing at different points along it. The amount of this filling within the area of the above computation is estimated as one square mile 900 feet thick or $\frac{9}{11}$ of the amount of rock excavation. Since the formation of these gravels the

stream has only partially removed this partial filling of the trench previously cut. The estimated amount of the material so removed since the time of the formation of the kettle moraine is one square mile 650 feet deep, or $\frac{13}{22}$ as much as the *rock* excavation. From this it appeared that the amount of erosion in all post-glacial time (including the last of the glacial period), although wrought upon incoherent gravels, is much less than the amount of rock cutting accomplished between the time the river was diverted and the formation of the kettle moraine.

In the introduction to his paper Professor G. Frederick Wright stated that the hypothesis of an ice dam at Cincinnati appeared to be in a damaged condition, as an agency to account for the high terraces of the upper Ohio and some of its tributaries, and that it was a part of the purpose of the paper to repair the damage. It proved in the sequel, however, an effort at emendation by substitution. The additional facts bearing upon the unity of the glacial period cited in the paper related chiefly to a considerable depth of glacial wash in the trench of a tributary of the Beaver River near Homewood, Pa., just outside but near the border of the glaciated region. Professor Wright contended that the trough in which this glacial material lies must have been eroded previous to its deposition. This erosion he referred to pre-glacial times. The filling reaches nearly or quite to the upper terrace plain on the north side of the tributary, but does not appear on the terrace plain south of the tributary. In the course of his paper, and notably in the discussion following, Professor Wright advanced the hypothesis that the rock shelves which constitute the base of the high terraces of the upper Ohio, Allegheny and adjacent rivers, were formed during a stage of base-levelling in Tertiary times, that the narrower and deeper valley below the rock shelves (in round numbers 300 feet deep) was cut in this base-plane during a stage of elevation just preceding the glacial period, and that this trench was filled up with glacial wash and glacio-natant material to a height, at some points, as much as sixty feet above the rock shelves. In the discussion it was pointed out that, to

account for the fact that the trains of gravel that rise on the outer face of the adjacent moraines run down through this narrower deeper valley at low levels, it is necessary to suppose that there was an interruption of glacial action and a period of excavation during which the previously formed 300 feet or more of glacial wash was very largely carried away, and that this means a discontinuity of glacial action and an interglacial interval. The hypothesis is, therefore, not a contribution to unity but to discontinuity. The amount of excavation between the time of the supposed first filling of the trench and the partial refilling at the time of the formation of the adjacent terminal moraine was several times greater than all that has taken place since the moraine was formed. It signifies, therefore, a very notable interruption of continuity and a reversal of action. It may be here added that, logically, it also means the abandonment of the "fringe" theory to account for the older drift, for the filling of the valleys for so great distance and to so great depth means more than a trivial stage of advance, and the excavation previous to the formation of the moraine means more than a slight stage of recession.

Mr. Leverett has examined the Homewood locality since the meeting, and became satisfied that the partial filling of the trench at that point took place contemporaneously with a moraine which crossed the valley only a short distance above (some miles outside the glacial boundary as mapped by Lewis and Wright, and even some distance beyond the striæ not long since reported by Dr. Forshay, Mr. Leverett finding striation half a mile farther down the valley). The characteristics of this moraine seem to Mr. Leverett to indicate that it belongs to the group formed during the later incursion. The shelf of rock south of the tributary was not covered by the glacial wash of this stage because the trench lacked about twenty feet of being filled by the wash. Mr. Leverett found other remnants which he regards as parts of the same glacial flood-deposit farther down the Beaver, the surface rapidly descending as is the habit of such moraine-headed terraces near their sources. The facts

here, therefore, appear to be essentially the same as on other tributaries of the region which are crossed by the group of later moraines, and which seem to indicate profound excavation between the earlier and later drifts.

The hypothesis advanced in the paper, while not new in itself, having been among the multiple working hypotheses used by one or more students of the region, though not so far as known adopted by any one previously, is much more deserving of serious consideration than its predecessor, the Cincinnati ice dam. It may have some elements of truth in it, *i. e.*, a portion of the excavation of the rock below the old base-plane may have preceded the incursion of the glacial wash and even the glacial period. If this should prove true the effect will be to extend the importance of the earlier glacial epoch and to reduce the time necessarily attributed to the interglacial interval of excavation. The glacial formations of the lower Ohio and adjacent regions, however, seem to indicate a more complex hypothesis than this, or any previously advanced, which shall take cognizance of more than one glacial episode previous to the formation of the well-developed terminal moraines.

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ONE session of the Geological Section was adjourned to permit members to listen to papers read before the Anthropological Section having a geological bearing. These were the "Evidence of Glacial Man in America," by G. Frederick Wright; and "The Antiquity of Man in America," by W J McGee. The former consisted essentially of a restatement of the supposed evidences of the existence of man contemporaneously with the glacial period found in the terraces at Madisonville and Newcomerstown in Ohio, and at Trenton, N. J. The latter consisted essentially of a discussion of the character of evidence required for the establishment of the antiquity of man. Emphasis was especially laid upon the distinction between legal evidence and scientific evidence.

In the first paper no new discoveries were announced nor any additional data of note added to previous evidence. On

the other hand, the localities of Little Falls, Minn., Medora, Ind., and Loveland, Ohio, which have recently been urged as offering evidence of glacial man, were passed in silence. The paper referred constantly to the chipped stones as "paleolithic implements," and ignored the recent issue raised by Professor Holmes' investigations which are thought by many to make it probable that, whatever their geological age, the chipped stones are rejects and failures incident to the process of neolithic manfacture, and are therefore neither "paleolithic" nor "implements" in the proper sense of the terms. In the discussion, attention was called to the significant omission of three out of six of the localities which a year ago were urged as furnishing evidence of glacial man. Attention was called to the Ohio exhibit in the Anthropological Department of the Exposition in Chicago as furnishing proof that the testimony relating to the Newcomerstown locality cannot be accepted as having scientific value, because the point marked upon the photographs of the exhibit as being the location of the find cannot be rationally supposed to be the actual locality. Considerable discussion also turned upon the possibilities of intrusion, particularly through the agency of the growth and decay of the roots of successive generations of forests. It was urged that, allowing not more than six thousand years since the close of the glacial period, and allowing one hundred years for a generation of trees, sixty generations may have grown in succession. In the process of the growth of the large roots of the trees, the gravels and other material were pressed laterally and to some extent upward by their expansion, and on the decay of the roots the space they occupied was refilled, presumably from above, in part at least. In the case of trees which have tap roots the penetration is deep, particularly on gravel terraces where the substratum is porous and relatively dry and the ground-water far below the surface. It was urged that, in the refilling of the numerous tubes formed by the growth and decay of the roots of so many generations of trees, opportunities would be afforded for the occasional and sometimes deep penetration of relics that were originally

deposited at or near the surface. It was objected that the tubes formed by roots would be closed in by lateral creep and not from above. This, it may be here remarked, would depend upon whether the lower part of the root decayed before the upper part, or whether the decay proceeded from the surface downward. It would also depend upon whether the exterior of the roots rotted first or whether the bark resisted decay longest, leaving the interior, at a certain stage, practically hollow. It would appear that this subject has not received adequate attention, and that careful investigations respecting the growth and decay of roots in such situations should be made, and the possibilities of intrusion by means of them carefully determined. Reference was also made to the possibilities of intrusion through the agency of a similar succession of generations of burrowing animals. In view of the fact that in the paper under discussion only about twenty flaked stones of artificial origin were insisted upon as occurring deep within the gravels, the question of the possibilities of intrusion assumes very considerable importance. A certain amount of intrusion can fairly be claimed as probable. The vital question is, Can it be presumed to account for all cases not otherwise accounted for?

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THE admirable address of the retiring President of the American Association, Dr. LeConte, appears in this number of the JOURNAL and needs no comment. We hope to publish Vice-President Walcott's address in our next number.

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THE Woman's Section of the Geological Congress at Chicago, assembled on Monday, August 21, and held short sessions throughout the week. The following is the list of papers:

Methods of Teaching Geology, by Miss Mary Holmes, Ph.D., Rockford, Ill.; Physical Geology, by Miss Mary K. Andrews, Belfast, Ireland; Chemical Geology, by Miss Louise Foster, Boston, Mass.; Granites of Massachusetts and Their Origin, by Mrs. Ella F. Boyd, Hyde Park, Mass.; Artistic Geology, by

Mrs. S. Maxon-Cobb, Boulder, Colo.; The Geology of Ogle County, by Mrs. C. M. Winston, Chicago; The Fossils of the Upper Silurian, by Mrs. Ada D. Davidson, Oberlin, Ohio; Crinoidea and Blastoidea of the Kinderhook Group as found in the Quarries near Marshalltown, Iowa, by Jennie McGowen, A.M., M.D., Davenport, Iowa; The Evolution of the Brachiopoda, by Miss Agnes Crane, Brighton, England; The Mastodon in Northern Ohio; Post-Glacial or Pre-Glacial? by Miss Ellen Smith, Painesville, Ohio; Palæontology, by Miss Jane Donald, Carlisle, England; Glacial Markings, by Miss Thomson, Newcastle, England.

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THE general session of the Geological Congress convened at Chicago on August 24, immediately following the close of the meeting of the American Association at Madison.

The Congress was welcomed felicitously by the President of the Auxiliary, Charles C. Bonney, and briefly by the Chairman of the Committee on Organization.

Dr. A. R. C. Selwyn presided over the first session; Pro fessor Joseph LeConte and Mr. Hjalmar Lundbohm, of Sweden, over the second session; and Professor James Hall and Dr. Groth, of Munich, over the third. The following papers were presented:

Pre-Cambrian Rocks of Wales, Dr. Henry Hicks, London, England; The Classification of the Rock Formations of Canada, with Special Reference to the Paleozoic Era, by Henry M. Ami, Geological Survey of Canada; The Cordilleran Mesozoic Revolution by Dr. A. C. Lawson, University of California; The Oil Shales of the Scottish Carboniferous System, by Henry M. Cadell, late of the Geological Survey of Scotland; Distribution of Pre-Cambrian Volcanic Rocks along the Eastern Border of the United States and Canada, by Professor George H. Williams, Johns Hopkins University; Huronian versus Algonkian, by Dr. A. R. C. Selwyn, Director Geological Survey of Canada; On the Migration of Material during the Metamorphism of Rock Masses, by Alfred Harker, St. John's College, Cambridge, Eng-

land; Wave-like Progress of an Epeirogenic Uplift, by Warren Upham, Geological Survey of Minnesota; Zur Nereiten Frage, by Dr. H. B. Geinitz, Dresden; Genetic Classification of Geology, by W J McGee, Bureau of Ethnology; The Extent and Lapse of Time Represented by Unconformities, by Professor C. R. Van Hise, U. S. Geological Survey; Restoration of Clidastes (illustrated), by Professor S. W. Williston, University of Kansas; Glacial Succession in the British Isles and Northern Europe, by Dr. James Geikie, Geological Survey of Scotland; Glacial Succession in Sweden, by Hjalmar Lundbohm, Geological Survey of Sweden; Glacial Succession in Switzerland, by Dr. Albrecht Heim, Zurich; Glacial Succession in Norway, by Dr. Andr M. Hansen, Geological Survey of Norway; The Succession of the Glacial Deposits of Canada, by Dr. Robert Bell, Canadian Geological Survey; Glacial Succession in the United States, by Dr. T. C. Chamberlin, University of Chicago; Pleistocene Climatic Changes, by Warren Upham, Geological Survey of Minnesota; Evidences of the Diversity of the Older Drift in North-western Illinois, by Frank Leverett, U. S. Geological Survey. A paper on the General Geology of Venezuela, by Dr. Adolph Ernst, was omitted on account of the illness of its author; and two papers by Dr. O. A. Derby, entitled, On the General Geology of Brazil, and On the Eruptive Phenomena of Brazil, were omitted because their author did not arrive until after the session. Four other papers announced were not read.

The latter part of the first session was devoted to a general discussion of the question, *Are there any Natural Geological Divisions of World-wide Extent?* The latter part of the second session was devoted to the question, *What are the Principles and Criteria to be observed in the Restoration of Ancient Geographic Outlines?* The general question assigned for the third discussion, *What are the Principles and Criteria to be observed in the Correlation of Glacial Formations in Opposite Hemispheres?* was omitted to give time for the discussion of the preceding glacial papers.

Several of the papers read will appear in this JOURNAL, and some of the matters touched upon in the discussions may be the

subjects of subsequent comment. About one hundred geologists were in attendance, a number which, under all the circumstances, was greater than was anticipated.

The afternoons of each day were devoted to the Exposition. Superintendent F. J. V. Skiff, Chief of the Department of Mines and Mining, and his associates, gave the members of the Congress a very pleasant welcome on their initial visit and provided special privileges of inspection that were heartily appreciated.

T. C. C.

REVIEWS.

Eruptive Rocks from Montana. By WALDEMAR LINDGREN. Proc. Cal. Acad. Sci. Ser. 2, Vol. 3. 1890.

A Sodalite-Syenite and other Rocks from Montana. By W. LINDGREN, with analyses by W. H. MELVILLE. Am. Jour. Sci. Vol. 45. April 1893.

Acmite-Trachyte from the Crazy Mountains, Montana. By J. E. WOLFF and R. S. TARR, Bull. Mus. Camp. Zoölogy, Harvard College. Vol. 16, No. 12. (Geological Series, Vol. 2).

Contributions to our knowledge of the mineral and chemical composition as well as the relationships of the igneous rocks of particular regions, however fragmentary, are of the greatest importance; especially when they relate to the vast areas of North America which remain almost unknown to the petrologist. The exploration of the great belt of country, one hundred miles wide, extending from California to Colorado and Wyoming along the fortieth parallel of latitude, by the geologists under Mr. Clarence King, constitutes the one great systematic study of the volcanic rocks of any considerable area on this continent. Less extensive investigations of smaller areas, isolated from one another and often separated by long distances, have been made from time to time, and to some extent have been published. But a large part of the work already done has not yet been printed. The facts so far brought to light show that the rocks of the Great Basin and the Pacific coast differ as a whole from those occurring in the eastern portion of the Rocky mountains and the region immediately east of it. This difference consists mainly in the greater abundance of the alkali-bearing rock-making minerals in the rocks of the latter region, caused by the relatively higher percentage of sodium or potassium in the magmas from which they have been derived.[1]

The recent papers by Mr. Lindgren and by Messrs. Wolff and Tarr illustrate this characteristic of the volcanic rocks of Montana along the frontal ranges of the Rocky mountains. All of the rocks described occur as intrusive bodies; laccolites, sheets, dikes or necks. They

[1] J. P. IDDINGS: The Origin of Igneous Rocks. Bull. Phil. Soc. Washington, Vol. 12, pp. 138, 139, 184.

were erupted in early Tertiary or late Cretaceous time in most cases, but their exact date is not known. Owing to extensive erosion the extrusive forms of these rocks, if they ever reached the surface, have been entirely removed.

Mr. Lindgren observes in the first paper cited that the rocks of this region appear to be more varied in chemical composition than the series usually found in the Great Basin; magmas rich in potassium are frequent, crystallizing as trachytes; often they are very basic, and contain much sodium, resulting in the abundant separation of such minerals as nepheline, sodalite and analcite.

The more or less acid rocks in the Little Belt mountains and at various points in front of the main range, west of Fort Benton, constitute dacites, hornblende-andesites, and diorites. Similar rocks also occur in the Moccasin mountains. They vary much in structure and composition, and form a natural group. The prevalent habit is porphyritic, but there appears to be a continuous series of transitions from porphyritic to fine granular rocks. The phenocrysts are feldspar and hornblende, and sometimes quartz and mica. The porphyritical feldspars are in part orthoclase in varying quantities, and there is reason to believe that these rocks pass by gradual transitions into trachytic and rhyolitic forms.

Those varieties free from phenocrysts of orthoclase and quartz grade into medium grained diorite, analogous to Stelzner's "Andendiorit," which contain besides plagioclase, hornblende and biotite, a little orthoclase and quartz as the last minerals to crystallize.

Of the more basic rocks, a part are syenites and trachytes, and a part basalts. The syenites which form dikes consist principally of orthoclase, plagioclase, biotite and a pyroxene, probably malacolite. They are called augite-syenites. The syenite from near Dry Fork, Little Belt mountains, contains, in addition to these minerals, allotriomorphic grains of an isotropic substance, probably sodalite. The rock contains 5.50 per cent. of K_2O, and 4.14 per cent. of Na_2O. The augite-syenite from the Highwood mountains is coarsely granular, and contains 5.66 per cent. of K_2O and 7.88 per cent. of Na_2O. This syenite is surrounded by trachytic and basaltic dikes; and in one case a dike of syenite was seen cutting one of the basaltic dikes.

The syenite from Square Butte at the northern end of the Highwood mountain is characterized by a noticeable percentage of sodalite and analcite, and has been called sodalite-syenite. Its chief constit-

uents are orthoclase, albite and hornblende. The relative proportions of the minerals has been estimated to be: orthoclase, 0.50; albite, 0.16; hornblende, 0.23; sodalite, 0.08; analcite, 0.03. The hornblende was analyzed and found to correspond to barkévikite. Mr. Lindgren calls attention to the resemblance in chemical composition between this rock and many nepheline-syenites, except for the relatively higher percentage of K_2O in the rock from Square Butte. He also notices the striking similarity between the analysis of this rock and those of certain leucitophyres from Rocca Monfina, and remarks that under different conditions the same magma, now crystallizing as a sodalite-syenite, might have produced a leucite-feldspar rock.

Trachytic rocks, with a great variety of habits, are abundant in the Highwood mountains. The essential minerals are sanidine and augite, with less prominent biotite. The augite is deep green, often somewhat pleochroic, and evidently contains an admixture of the ægirine molecule. It is very characteristic not only of the trachytes but also of the basaltic dike rocks of this region. These rocks form a connected series, the members of which differ in the relative quantities of augite and sanidine composing them. At one end of the series is a rock consisting almost wholly of feldspar, and at the other end a dark basaltic rock with porphyritical augites and a groundmass of sanidine and augite. In structure these rocks range from holocrystalline and granular to glassy. Some of the trachytes contain small crystals of sodalite (?) inclosed in sanidine. In one form of the rocks sanidine ceases to be the prominent phenocrysts and augite takes its place, and olivine occurs in the groundmass, which consists of feldspar and colorless glass easily soluble in HCl. Associated with the sodalite-syenite of Square Butte are dark colored basaltic rocks, which occur in three sheets at the base of the butte. Surrounding the butte there are numerous dikes apparently radiating from the central mass. One of these basaltic sheets contains phenocrysts of augite, olivine, brown mica, and white isometric crystals whose original character is uncertain. The rock is considerably decomposed. Another of the sheets is like analcite-basalt but is also decomposed. The third is coarsely granular and approaches theralite in composition.

The rocks described as analcite-basalts occur in dikes and possibly as necks in association with the rocks already described. They consist of augite, olivine, magnetite, and a mineral, which from its form and optical properties, and from its chemical composition appears to

be analcite. Biotite is sometimes present in small quantities. From the very fresh appearance of these rocks it seems probable that the analcite is a primary crystallization from the molten magma. The groundmass of the rock consists of augite and small crystals of analcite with magnetite. Mr. Lindgren calls attention to the difficulty of distinguishing glass, if present, from isotropic analcite.

In the Bear Paw mountains there are dikes of rocks related to those just described and which correspond to the lamprophyres of Rosenbusch. They are dark, fine grained, and porphyritic with phenocrysts of augite and long flakes of brown mica. The groundmass consists mostly of lath-shaped plagioclase, augite and mica. Some varieties with phenocrysts of olivine and augite, in a glassy groundmass without feldspar, approach certain limburgites.

The paper by Messrs. Wolff and Tarr is confined to a description of certain trachytic and syenitic rocks in the Crazy mountains. The first notice of the interesting rocks of this locality was published by Mr. Wolff in 1885, and he has since undertaken a much more extensive investigation of the same group of rocks, which is not yet completed. The trachytes form dikes, sheets and laccolites in the northern portion of the range, and are associated with theralite. Like the theralites and some other rocks of this range, they are coarse grained, almost granitic when in thick sheets, fine grained and porphyritic in the smaller sheets, dikes, and apophyses. When occurring in the latter forms the rocks have a trachytic habit, and are called acmite-trachyte. The phenocrysts are glassy feldspar, augite and small sodalites. Biotite is scarce. The feldspar is soda-microcline or anorthoclase. The augite is pale green at the center, and becomes dark green at the margin, where the optical characters are those of aegirine, similar to that in the theralite. The groundmass consists essentially of lath-shaped feldspar and acicular crystals of aegirine. With the green aegirine a few brown needles of acmite occur. There is a variable amount of interstitial matter between the feldspars of the groundmass which is probably nepheline in part, and partly analcite, derived from the alteration of the nepheline.

The coarse grained forms of the rock, or syenite, consist of the same essential minerals as the trachytic varieties. Sodalite is rare in the coarse rocks, and acmite is not always present. Chemical analyses of these rocks are published, but the discussion of them is postponed until the monograph of the whole group of rocks is pre-

pared. The resemblance between certain features of the rocks of Montana and those from Arkansas, described by J. Francis Williams, is pointed out by each of the writers cited. The resemblance to the lamprophyric rocks in the Absaroka range, Wyoming, east of the Yellowstone National Park, is also noticed.

Some of the petrographical characteristics of the rocks of this region are: The prevalence of orthoclase in many intermediate and basic rocks, leading to the frequent occurrence of trachyte and syenite and some forms of lamprophyre, as well as its presence in prominent crystals in the andesites and porphyrites, and the frequent occurrence of dark green augite and aegirine, and occasionally of acmite.

The difficulty of distinguishing colorless glass from isotropic analcite, both of which may occur in certain varieties of lamprophyre, makes it necessary to use the greatest care in determining the character of the apparent base in these forms of rocks. It seems probable to the reviewer that in some instances, in which an amorphous glass has been described as forming the matrix of the microscopic crystals in some lamprophyric dike rocks, it will be found that a definite isotropic alkali mineral is present, and that the rock is holocrystalline

JOSEPH P. IDDINGS.

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GEOLOGIC TIME, AS INDICATED BY THE SEDIMENTARY ROCKS OF NORTH AMERICA.*

INTRODUCTION.

OF ALL subjects of speculative geology few are more attractive or more uncertain in positive results than geologic time. The physicists have drawn the lines closer and closer until the geologist is told that he must bring his estimates of the age of the earth within a limit of from ten to thirty millions of years. The geologist masses his observations and replies that more time is required, and suggests to the physicist that there may be an error somewhere in his data or the method of his treatment. The geologist realizes that geologic time cannot be reduced to actual time in decades or centuries; there are too many partially recognized or altogether unknown factors; but he can approximate the relative position of certain formations, and by comparison of their sediments, dimensions, and contained record of life with estimated rates of denudation, sedimentation and organic growth, form a general estimate of their relative time duration. It is my purpose to-day to take up the consideration of the evidence afforded by the sedimentary rocks of our continental area, and largely of a distinct basin of sedimentation, with a view of arriving, if possible, at an approximate time-period for their deposition. Before so doing, I will briefly refer to a few of the opinions that have been held by geologists on geologic

* Vice-Presidential address delivered before Section E, Am. Assc. Adv. Sci., Madison, Wis., August 17, 1893.

time and the age of the earth. Soon after geology emerged from its pre-systematic stage, in the latter part of the eighteenth century, and assumed an independent position among the inductive sciences speculations on the age of the earth began. Dr. James Hutton, the founder of modern physical geology, and the predecessor of Lyell, in advocating the uniformitarian theory, was the first to argue that the rate of destruction of one land area was the means of measuring the duration of others, and that the continents were formed of the ruins of pre-existing continents, but that in our measurement of time such periods were of indefinite duration.[1] It was not, however, until 1830, when Sir Charles Lyell published the results of his profound and philosophic studies of geologic phenomena, that the broad outlines of the law of uniformity, as opposed to the doctrine of geologic catastrophes, was fairly established. This work rendered possible a computation of the age of the earth on the principle that geologic processes were the same in the past as at present. He based his estimate of time on a rate of modification of species of mollusca since the beginning of the "Cambrian period," and divided the geologic series into twelve periods, assigning 20,000,000 years to each for a complete change in their species,—or 240,000,000 years in all. This estimate excluded the "antecedent Laurentian formation."[2]

The hour at our disposal does not permit of mentioning at length the views of other geologists. Dr. Charles Darwin thought that 200,000,000 of years could hardly be considered sufficient for the evolution of organic forms,[3] and Rev. Samuel Haughton assigned 1,280,000,000 of years to pre-Azoic time, and remarked that the globe was habitable, in part at least, for a longer period.[4] At a later date he estimated a minor limit to

[1] Theory of the Earth; or an Investigation of the Laws observable in the Composition, Dissolution, and Restoration of Land upon the Globe. Trans. Royal Soc. Edinburgh, Vol. I., 1788, pt. 1, p. 304.

[2] Principles of Geology, 10th Ed., Vol. I., 1867, p. 301.

[3] Origin of Species, American Ed., from 6th Eng. Ed., 1882, p. 286.

[4] Manual of Geology, 3rd Ed., 1871, p. 101.

geologic time of 200,000,000 of years.[1] Dr. James Croll estimated 72,000,000 years for the time duration since the first deposition of sedimentary rocks, while Sir Alfred R. Wallace thought that 28,000,000 years would suffice.[2] Of the value of this estimate he says: "It is not of course supposed that the calculation here given makes any approach to accuracy, but it is believed that it does indicate the order of magnitude of the time required."[3] Dr. Alexander Winchell reduced geologic time still more in his estimate of 3,000,000 years for the whole incrusted age of the world.[4] Later writers, however, do not accept this, as we find Sir Archibald Geikie concluding on the basis of denudation and deposition that the sedimentary rocks would have required 73,000,000 of years for their deposition, if denudation was at the rate of one foot in 730 years; or of 680,000,000 of years if at the slower rate of one foot in 6,800 years.[5] Mr. T. Mellard Reade adopted one foot in 3,000 years as the rate of average denudation throughout geologic time, and obtained a result of 95,000,000 of years as the time that had elapsed since the beginning of Cambrian time.[6] M. A. de Lapparent is one of the few European continental geologists that has written on geologic time. On the basis of mechanical denudation and sedimentation he thinks that from 67,000,000 to 90,000,000 of years would suffice, at the present rate of sedimentation for everything that has been produced since the consolidation of the crust.[7] The two most recent writers who have taken their initial datum point or "geochrone" from the consideration of late Cenozoic or Pleistocene phenomena

[1] Nature, Vol. 18, 1878, pp. 267–268.

[2] Stella Evolution and its Relations to Geological Time, 1889, pp. 48–49.

[3] Island Life, 2d. Ed., 1892, pp. 222–223.

[4] World Life, or Comparative Geology. Chicago, 1883, p. 378.

[5] Presidential Address; report of 62d meeting British Assoc. Adv. Sci., 1892, p. 21.

[6] Measurement of Geological Time. Geol. Mag., Vol. 10, 1893, pp. 99–100.

[7] De la mesure du temps parles phénomènes de sédimentation. Bull. Soc. Geol. France, 3d ser., Vol. 18, 1890, pp. 351–355. La Destinée de la terre férme et durée des temps geologiques. Revue des questions scientifiques, July, 1891. Pamphlet. Bruxelles. Pp. 1–38.

have differed materially in their results. Mr. W J McGee estimated that the mean age of the earth is 15,000 million years, and that 7,000 million had elapsed since the beginning of Paleozoic time.[1] In a subsequent note he modifies this conclusion and gives as a mean estimate 6,000 million years, of which 2,400 million have elapsed since the beginning of the Paleozoic. This is based on a minimum estimate of the age of the earth of 10,000,000 years and a maximum estimate of five million million (5,000,000,000,000) years.[2] Professor Warren Upham concludes that Quartenary time comprises about 100,000 years. He applies Professor Dana's time-ratio, and finds on this basis that the time needed for the earth's stratified rocks and the unfolding of its plant and animal life must be about 100 millions of years.[3]

From the foregoing estimates of geologic time the only conclusion that can be drawn is that the earth is *very old*, and that man's occupation of it is but a day's span as compared with the eons that have elapsed since the first consolidation of the rocks with which the geologist is acquainted.

When I began the preparation of this paper it was my intention to carefully analyze the sedimentary rocks of the entire geological series as exposed upon the North American continent. I soon found, however, that the time at my disposal would make this impracticable, and I decided to take up the history of the deposits that accumulated in Paleozoic time on the western side of our continent, in an area that for convenience I shall call the Cordilleran sea. This was chosen as (1) I was personally acquainted with many of its typical sections; (2) there was a broad and almost uninterrupted sedimentation during Paleozoic time; and (3) there is a prospect for obtaining more satisfactory data as a basis of calculation, since calcareous deposits are in excess of those of mechanical origin.

We will now consider certain points in relation to the growth

[1] American Anthropologist, Vol. 5, 1892, p. 340.

[2] Science, Vol. 21, 1893, p. 309.

[3] Am. Jour. Sci., Vol. 45, 1893, pp. 217–218.

or evolution of the North American continent, as the deposition of mechanical sediments depends to a considerable extent on the character of the adjoining land area, and chemical sedimentation is also influenced by it.

GROWTH OF THE CONTINENT.

The Algonkian sediments were deposited in interior and bordering seas that filled the depressions and extended over the margins of the American continent. From the great thickness of mechanical sediments it was evidently a period of elevated land and rapid denudation. With the close of Algonkian time extensive orographic movements occurred that outlined the subsequent development of the continent. The lines of the Rocky Mountain and Appalachian ranges were determined, and the great basins of sedimentation west of them defined. Subsequent movements have elevated the old and formed new sub-parallel ranges. These movements were often of long duration and also separated by great intervals of time, as is shown by the long-continued base levels of erosion during which the great thickness of calcareous deposits accumulated in the Cordilleran and Appalachian seas. Since Algonkian time the growth of the continent has been by the deposition of sediments in the bordering oceans and interior seas and lakes within the limits of the continental plateau; and it is considered that the relative position of the continental plateau and the deep sea have not materially changed during that period. How much the deposits on the continental border have increased its area is unknown, as at present they are largely concealed beneath the waters of the ocean. During Paleozoic time the two areas of greatest known accumulation were in the Appalachian and Cordilleran seas, where 30,000 feet or more of sediments were deposited. In the Cordilleran sea sedimentation was practically uninterrupted (except during a short interval in middle Ordovician time) until towards the close of Paleozoic time. In the northern Appalachian sea it continued without any marked unconformity, from early Cambrian to the close of Ordovician time, and, south of New York, with

relatively little interruption, until the close of Paleozoic time. Certain minor disturbances occurred along the eastern border of the sea, but they were not of sufficient extent to affect a general conclusion—which is, that the depression of the areas of deposition within the continental platform continued without reversal of the subsidence during Paleozoic time. During Cambrian, and it may be late Algonkian time, the extended interior Mississippian region was practically leveled by denudation, the eroded material being carried into the Cordilleran and Appalachian seas, and, probably, to a sea to the south.

The sedimentation of the Mississippian area in Paleozoic time, between the Appalachian and the Cordilleran seas, was small as compared to that which accumulated in the latter. In Devonian time there does not appear to have been any sedimentation in the western portion of it west of the 94th meridian and east of the Cordilleran sea, and it was slight in the same interval in the Appalachian sea south of the 37th parallel.[1] There is little if any evidence in the sediments of Paleozoic time to show that they were deposited in the deep, open ocean; on the contrary, they were largely accumulated in partially enclosed seas or mediterraneans and on the borders of the continental plateau. The former is particularly true of the sedimentation of the Cordilleran and Appalachian seas and the broad Mississippian sea.

The close of the prolonged period of Paleozic sedimentation was brought about by what Dana has termed the "Appalachian revolution." The topography of the continent was more or less changed, and the conditions of sedimentation that followed were unlike those that preceded. This revolution raised above the sea level a considerable portion of the Cordilleran and the Appalachian sea-beds and also of the Mississippian sea, east of the 96th meridian and north of the 34th parallel.

[1] The non-occurrence of Devonian sediment has not yet been fully explained. It has been suggested that the sea beyond the reach of mechanical sedimentation was too deep for the deposition of calcareous deposits. It is more probable that the sea was shallow and an area of non-deposition, or that its bed was raised to form a low, level land surface at a base level of erosion that was subjected to very slight degradation.

In its effect it may be compared to the Algonkian revolution[1] that preceded the deposition of the Paleozoic sediments.

With the opening of new conditions the sedimentation of Mesozoic time began upon the Atlantic border and over large areas of the western half of the continent with the deposit of mechanical sediments—sands, silts, etc.—during Jura-Trias time. They are of a character that naturally follows a period of disturbance of pre-existing conditions, and the formation of new basins of deposition with more or less elevated adjoining land areas. At its close orographic movements affecting the positions of the beds occurred upon the Pacific and Atlantic coasts, and also, to a more limited degree, throughout the Rocky mountain region. This does not appear to have extended over the plateau region or the central belt between the 97th and 105th meridians.

The Cretaceous formations have their greatest development between the 97th and 112th meridians in Mexico and the United States, in a broad belt which extends from the boundary of the latter to the northwest into the British Possessions as far as the 61st parallel. They were of a marine origin until towards the close of the period when a prolonged orographic movement elevated a large area of the continent above sea level, and locally upturned the Cretaceous strata in the Rocky mountain area. The shoaling of the sea was followed by the formation of great inland lakes, in which fresh water deposits succeeded the marine and estuarian sediments. Over the coastal regions they were of marine origin throughout.

The Tertiary sediments deposited on the Cretaceous are marine on the Atlantic, Gulf of Mexico, and Pacific coasts, and of fresh-water origin in the Rocky mountain and Great Plains areas—where they were deposited in the great inland lakes outlined in the previous period.

[1] The term revolution is used to describe the culmination of a long series of phenomena that finally resulted in a distinctly marked epoch in the evolution of the continent. The "Appalachian revolution" began far back in the Paleozoic, and culminated in the later stages of the Carboniferous and the Algonkian revolution, probably began far back in Algonkian time.

GEOGRAPHIC CONDITIONS ACCOMPANYING THE DEPOSITION OF PALEOZOIC SEDIMENTS IN THE CORDILLERAN SEA.

The assumed area of the Cordilleran or Paleo-Rocky mountain sea includes over 400,000 square miles between the 35th and 55th parallels. To the eastward during lower and middle Cambrian time a land area is thought to have extended from east of the 111th meridian across the continent to the Paleo-Appalachian sea. This land was depressed toward the close of middle Cambrian time, and the Mississippian sea expanded over the wide plateau-like interior region, from the Gulf of Mexico on the south to the Lake Superior region on the north; westward it penetrated among the mountain ridges between the 105th and 111th meridians, laying down the upper Cambrian deposits that are now found in New Mexico, Arizona, eastern Utah, the western half of Colorado, Wyoming, Idaho and Montana, and still farther north into Alberta and British Columbia. During Ordovician, Silurian, Devonian, and Carboniferous time this entire Mississippian region, except portions in Devonian time, appears to have been covered by a relatively shallow sea that was co-extensive with the Appalachian sea and that communicated freely with the Cordilleran sea. During this same age, however, the Rocky mountain area of New Mexico, Colorado, Utah, Wyoming and Montana formed a more or less well-defined boundary of ridges and islands between the Cordilleran and the interior sea up to the 49th parallel. To the north of the latter the conditions appear to have been the same as on the eastern side of the continent, where the Appalachian sea communicated freely with the Mississippian sea. From the data that we now have I think that the Paleozoic (Mississippian) sea extended at times over nearly all of the area subsequently covered by the Cretaceous and the later formations between the Gulf of Mexico and the Arctic ocean. This belt is bounded almost continuously on the east and west by Paleozoic rocks that extend from the Arctic ocean to Mexico, and whether of Cambrian, Ordovician, Silurian or Devonian age they carry essentially the same fauna throughout their extent. In the outcrops of lower strata that rise up

through this Cretaceous area, the Cambrian, Ordovician, and Carboniferous rocks are found encircling the pre-Paleozoic rocks. Instances in which the Archean rocks have been met with immediately beneath the Cretaceous in borings in Dakota and Minnesota are along the eastern border of the area, next to the Archean rocks,—where it is probable that the Cretaceous overlaps the Paleozoic to the Archean.

The western side of the Cordilleran sea seems to have been bounded by a land area that separated it from the Paleozoic sea, which extended through central California and the Pacific border of British Columbia and Vancouver's Island. From the positions of the Carboniferous deposits of California at the present time it appears that this land varied from 100 to 150 miles in width and was practically continuous along the western side of the Cordilleran sea. This view is further strengthened by the fact that the Carboniferous fauna of California has certain characteristics which are not found in the Carboniferous of the Cordilleran area. Our knowledge of conditions north of the 55th parallel is limited by the want of accurate geologic data. If Cambrian and Carboniferous rocks were not deposited in the Mackenzie river basin and also on the eastern side of the area now covered by Cretaceous strata, the inference is that during Cambrian and Carboniferous time there was a land area to the east and north of the northern Cordilleran sea that may have been tributary to the latter.

SOURCE OF SEDIMENTS DEPOSITED IN THE CORDILLERAN SEA.

The sediments deposited in every sea or lake are derived from land areas either by mechanical or chemical denundation.

Mechanical denudation results from the action of the waves and currents along the shore and the agency of rain, frost, snow, ice, wind, heat, etc., on the land. Rain is the most important factor, and the result depends mainly upon its amount and the slope or the gradient of the land. The general average of denudation for the surface of the land areas of the globe, now usually accepted, is one foot in 3,000 years. This varies locally,

according to Sir Archibald Geikie, from one foot in 750 years to one foot in 6,000 years.[1] Of the rate of denudation during Paleozoic time about the Cordilleran sea we know very little, but I think that it was relatively rapid in early Cambrian time and during the deposition of the arenaceous sediments of the Ordovician and Carboniferous. The material forming the argillaceous shales of the Cambrian and Devonian was supplied to the sea more slowly. These conclusions are sustained by the slight change in the character of the faunas where interrupted by the sands and pebbles of the Ordovician and Carboniferous and the marked change between the base and summit of the argillaceous shales. As a whole I think we are justified in assuming a minimum rate of mechanical denudation—of considerably less than one foot in 1,000 years—for the area tributary to the Cordilleran sea.

Chemical denudation is the removal of material taken into solution by water. Mr. T. Mellard Reade has discussed this phase of denudation in an admirable manner.[2] He came to the conclusion, from what was known of the volume of water discharged into the ocean per year, the average amount of material in chemical solution and the area of land surface drained by the rivers, that an average of 100 tons of rocky matter is dissolved per English square mile per annum. Of this he says: "If we allot 50 tons to carbonate of lime, 20 tons to sulphate of lime, 7 to silica, 4 to carbonate of magnesia, 4 to sulphate of magnesia, 1 to peroxide of iron, 8 to chloride of sodium, and 6 to the alkaline carbonates and sulphates we shall probably be as near the truth as present data will allow us to come."[3] By the use of the data given by Mr. John Murray, in a paper on the total annual rainfall on the land of the globe, and the relation of rainfall to the discharge of rivers,[4] I obtain 113 tons as the total

[1] Brit. Assoc. Adv. Sci., Sixty-second Meeting, 1893, p. 21.

[2] Proc. Liverpool Geol. Soc., Vol. III., pt. 3, 1877, pp. 212–235. Chemical Denudation in Relation to Geological Time, 1879, pp. 1–61.

[3] Loc. cit., p. 229.

[4] Scottish Geol. Mag., Vol. III., 1887, pp. 65–77.

amount of matter in solution discharged into the Atlantic basin per annum from each square mile of area drained into it. Of this 49 tons consist of carbonate of lime and 5.5 tons of sulphate and phosphate of lime.[1]

Mechanical Sediments.—With the geographic conditions described as prevailing during Paleozoic time, the source of mechanical sediments later than the Middle Cambrian must have been from the broken area on the eastern side that extended 100 to 200 miles to the eastward and to a much greater extent from the land along the western side of the sea. The enormous deposit of from 10,000 to 20,000 feet of mechanical sediments in early Cambrian time is explained by the assumption of favorable topographic conditions of denudation following the Algonkian revolution and the presence of a land area over the interior portion of the continent, and also, in all probability, between the western side of the Cordilleran sea and the western border of the continent. During this period the conformable pre-fossiliferous strata of the Cambrian accumulated and about 6,000 feet of the lower fossiliferous rocks as they occur in the Eureka district of central Nevada. Following the depression of the continent, which carried down the central area and also introduced the upper Cambrian (Mississippian) sea into the Rocky mountain area of Colorado, etc., there were deposited of mechanical sediments in central Nevada:

Ordovician sands, - - - - - -	500 feet.
Devonian fine argillaceous muds, - - -	2,000 "
Lower Carboniferous sands, - - - -	3,000 "
Upper Carboniferous conglomerate and sands, - -	2,000 "
	7,500 "

making a total of 7,500 feet of mechanical sediments, the remaining portion of the section (15,150 feet) being limestone.

The following table exhibits the relative thickness of

[1] Total amount removed in solution per annum by rivers, 762,587 tons per cubic mile of river water. Total discharge of river water per annum into the Atlantic, 3,947 cubic miles. Area drained, 26,400,000 square miles. Amount of carbonate of lime per annum, 326,710 tons per cubic mile of river water; of sulphate and phosphate of lime, 37.274 tons.

mechanical and chemical deposits in the Cordilleran sea after the middle Cambrian subsidence :

	Wasatch.	Central Nevada.	Southwest Nevada.	Montana.	Alberta.
Mechanical Sediment,	10,000	7,500	2,500	1,000	4,600
Chemical Sediment,	10,400	15,150	13,000	4,000	15,000
Ratio,	$\frac{1}{1}$	$\frac{1}{2}$	$\frac{1}{5}$	$\frac{1}{4}$	$\frac{1}{3}$

If an average is taken of the mechanical sediment deposited subsequent to the close of middle Cambrian time, it will be found to be about 5,000 feet for the entire area, which, I think, does away with any necessity to assume an additional hypothetical land area for the source of the mechanical sediment. The fine sand composing the quartzites and the silt forming the shales, as well as the fine conglomerate of later deposits, were derived from the adjoining land areas, and, in all probability, currents swept through from the ocean to the south or north, distributing the mud and sand contributed from the rivers and streams along the shores.

Chemical Sediments.—The present supply of the carbonate of lime, silica, etc., contained in sea-water is derived from waters poured into the sea by rivers and streams. The Cordilleran sea undoubtedly received a large contribution from the adjoining land areas, but a considerable amount was possibly derived from an oceanic current that circulated through it as the southern equatorial current of the Atlantic now sweeps through the Caribbean. From the vast deposits of carbonate of lime it might be assumed, *a priori*, that the waters of a Mississippi or Amazon were poured into it, but there is not any evidence of the existence of such a river, although the tributary area may have been very large in Cambrian and Carboniferous time, if the drainage of the country west of Hudson's Bay was to the westward.

Conditions of Deposition.—With free communication into the open ocean on the south, and probably on the north, during most of Paleozoic time strong currents must have circulated through the Cordilleran sea. The broad distribution of

mechanical sediments of a uniform character clearly shows this to have been the case, especially in pre-Silurian (Ordovician) time. The present known distribution of the mechanical sediments indicate that they were mainly brought into the sea from the west,[1] although a vast amount was derived from the land on the eastern side in pre-Ordovician time. They were quite evenly distributed over the sea bed, except where local accumulations of silt and sand occurred near the larger sources of supply, or in the direction of powerful currents within the sea.

The conditions of the deposition of the carbonate of lime are less clearly understood than those governing mechanical sediments, and I shall enter upon the discussion of them at considerable length. There are three methods by which it usually is considered that it may be deposited: 1. Agency of organisms; 2. Chemical precipitation; 3. By mechanical methods.

It is the general opinion of geologists that limestone rocks are the result almost entirely of the consolidation of lime removed from the sea water through the agency of life, and that they consist of the remains of foraminifera, crinoids, corals, etc., or their fragments, embedded in a more or less crystalline matrix resulting from subsequent alteration of the original deposits. This, however, has been seriously questioned. Sorby, in giving his general conclusions of an extensive microscopic examination of limestones, states that:

Even if it were possible to study in a detached state the finer granular particles which constitute so large a part of many limestone formations, it would usually be impossible to say whether they had been derived from organisms which can decay down into granules, or from other organisms which can only be worn down into granules, or from ground-down older limestone, or, in some cases, from carbonate of lime deposited chemically as granules. . . . . The shape and character of the identifiable fragments do, indeed, *prove* that much of this must have been derived from the decayed and worn-down calcareous organisms;

[1] Geol. Expl. Fortieth Parallel, Vol. I., 1878, p. 247.

and very often we may reasonably *infer* that the greater part, if not the whole, was so derived; but, at the same time, it is impossible to *prove*, from the structure of the rock, whether some or how much was derived from limestones or earlier date, or was deposited chemically, as some certainly must have been.[1]

In their memoir on coral reefs and other carbonate of lime formations in modern seas, Messrs. Murray and Irvine show that temperature of the water has a controlling influence upon the abundance of species and individuals of lime-secreting organisms; high temperature is more favorable to abundant secretions of carbonate of lime than high salinity.[2]

Taking the samples of deep sea deposits collected by the Challenger as a guide, the average percentage of carbonate of lime in the whole of the deposit covering the floor of the ocean is 36.83; of this it is estimated that fully 90 per cent. is derived from pelagic organisms that have fallen from the surface water, the remainder of the carbonate of lime having been secreted by organisms that laid on, or were attached to, the bottom. The estimated area of the various kinds of deposits, the average depth, and the average percentage of carbonate of lime to each are shown in the following table:

TABLE showing the Estimated Area, Mean Depth, and Mean Percentage of $CaCO_3$, of the different Deposits.

Deposit.		Area square miles.	Mean depth in fathoms.	Mean per ct. of $CaCO_3$.
Oceanic Oozes and Clays	Red clay,	50,289,600	2727	6.70
	Radiolarian ooze,	2,790,400	2894	4.01
	Diatom ooze,	10,420,600	1477	22.96
	Globigerina ooze,	47,752,500	1996	64.53
	Pteropod ooze	887,100	1118	79.26
Terrigenous Deposits	Coral sands and muds,	3,219,800	710	86.41
	Other terrigenous deposits, blue mud, etc.	27,899,300	1016	19.20

Loc. cit., p. 82.

"We have little knowledge as to the thickness of these deposits, still such as we have goes to show that in these organic cal-

[1] Quart. Jour. Geol. Soc. London, Vol. 35, 1879, pp. 61–92.

[2] Proc. Roy. Soc. Edinburgh, Vol. 17, 1890, p. 81.

careous oozes and muds, we have a vast formation greatly exceeding in bulk and extent the coral reefs of tropical seas; they are most widely distributed in equatorial regions, but some patches of Globigerina ooze are to be found even within the Arctic circle in the course of the gulf stream."[1]

The percentage of carbonate of lime contained in deposits accumulating at different depths, as obtained from 231 samples collected by the Challenger, is shown in the following tabulation:

14	cases	under	500	fathoms,	m. p. c.	86.04
7	"	"	500 to 1000	"	"	66.86
24	"	"	1000 to 1500	"	"	70.87
42	"	"	1500 to 2000	"	"	69.55
68	"	"	2000 to 2500	"	"	46.73
65	"	"	2500 to 3000	"	"	17.36
8	"	"	3000 to 3500	"	"	0.88
2	"	"	3500 to 4000	"	"	0.00
1	"	"	4000	"	"	trace.

The fourteen samples under 500 fathoms are chiefly coral muds and sands, and the seven samples from 500 to 1000 fathoms contain a considerable quantity of mineral particles from continents or volcanic islands. In all the depths greater than 1000 fathoms the carbonate of lime is mostly derived from the shells of pelagic organisms that have fallen from the surface waters, and it will be noticed that these wholly disappear from the greater depths.[2]

By a series of experiments Messrs. Murray and Irvine found: "That although sea water under certain conditions may take up a considerable quantity of carbonate of lime in solution, yet it is unable permanently to retain in solution more than is usually found to be present in sea water, and it is owing to this that the amount of carbonate of lime is so constantly low. The reaction between organic matter and the sulphates present in sea water (to which we have referred) tends also to keep the amount of carbonate of lime in solution at about one-half (0.12 grms.) of what it might contain (0.28 grms. per litre). This peculiarity of sea water, in taking up a large amount of amorphous carbon-

[1] Loc. cit., pp. 82–83.

[2] Loc. cit., p. 84.

ate of lime and throwing it out in the crystalline form, accounts for the filling up of the interstices of massive coral with crystalline carbonate in coral islands and other calcareous formations, so that all traces may ultimately be lost of the original organic structure."[1]

The authors explain the disappearance of shells and lime deposits in the greater depths of the ocean by their being dissolved by the carbonic acid in the water, which is present in larger quantity at great depths and also is produced by the decomposition of the animal matter of the shell and of the various organisms living in the water and on the bottom. They conclude that:

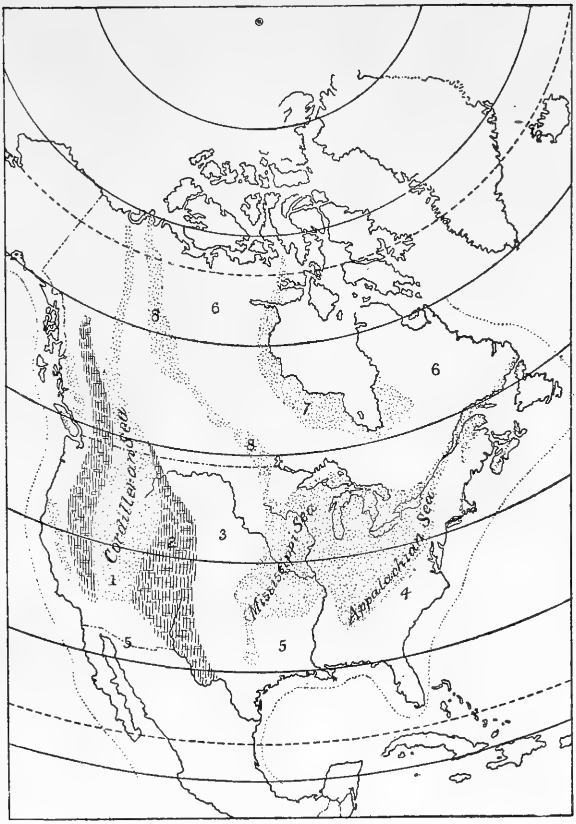
On the whole, however, the quantity of carbonate of lime that is secreted by animals must exceed what is re-dissolved by the action of sea water, and at the present time there is a vast accumulation of the carbonate of lime going on in the ocean. It has been the same in the past, for with a few insignificant exceptions all the carbonate of lime in the geological series of rocks has been secreted from sea water, and owes its origin to organisms in the same way as the carbon of the carboniferous formations; the extent of these deposits appears to have increased from the earliest down to the present geological period.[2]

In their report on deep sea deposits, collected by the Challenger Expedition, Messrs. Murray and Renard state that the chemical products formed in situ on the floor of the ocean nearly all originate in a sort of broth or ooze, in which the sea water is but slowly renewed. Many of them appear to be formed at the surface of the deposit—at the line separating the ooze from the superincumbent water, where oxidation takes place. In the deeper layers of the deposit a reduction of the higher oxides frequently occurs, and at the surface of the mud or ooze there are many living animals, as well as the dead remains of surface plants and animals.[3]

[1] Loc. cit., pp. 94–95.

[2] Loc. cit., p. 100.

[3] Report on the Scientific Results of the Voyage of M. M. S. Challenger. Deep-Sea Deposits, 1891, p. 337.



DESCRIPTION OF MAP.

On the map the hypothetical areas of the Cordilleran, Mississippian and Appalachian seas are clearly indicated. The land area west of the Cordilleran sea is numbered No. 1. The Californian sea and the area of Paleozoic deposits of western British Columbia No. 10. The northern extension of the Cordilleran sea (No. 9) is continued as the Paleozoic-devonian sea to the Arctic ocean. The early Cambrian land area (No. 2) east of the Cordilleran sea must have been more or less covered by water during later Paleozoic time. The area now covered by Mesozoic deposits, indicated by No. 3, was presumably covered by the westward and northward extension of the Paleozoic-Mississippian sea. The area east of the Appalachian sea is indicated by No. 4; and the supposed land barrier between the Hudson Bay and the Mississippian sea by No. 6; it is not improbable that during Ordovician or Silurian time a sea may have connected the two latter seas. The region to the south, indicated by No. 5, is supposed to have been covered by the southward extension of the Appalachian, Mississippian and Cordilleran seas. It is now covered by deposits of Mesozoic and Cenozoic seas.

A more detailed description of the map can be gained from the section on the growth of the continent and on the geographic conditions accompanying the different depositions of Paleozoic sediments in the Cordilleran sea.

They also conclude that practically all the carbon of marine organisms must ultimately be resolved into carbonic acid, the quantity of that acid produced in this way must be enormous, and cannot but exert a great solvent action not only on the dead calcareous structure, but also on the minerals in the muds on the floor of the ocean.[1] Of the effect of this destructive action, they say: "In all cases, however, calcareous structures of all kinds are slowly removed from the bottom of the ocean on the death of the organisms, unless rapidly covered up by the accumulating deposits, and in this way protected to a certain extent from the solvent action of the sea-water. It is evident from the Challenger investigations that whole classes of animals with hard calcareous shells and skeletons, remains of which one might suppose would be preserved in modern deposits, are not there represented; although they are now living in immense numbers in the surface waters or on the deposits at the bottom in some regions, yet all traces of them have been removed by solution. A similar removal of calcareous organic structures has undoubtedly taken place in the marine formations of past geologic ages.[2]

From the preceding statements it is evident that initially the greater part of the carbonate of lime is taken from the sea water by organic agency, but in the working over of this material in the chemical laboratory at the bottom of the sea a considerable portion is taken up by the sea water as amorphous carbonate of lime and thrown out in the crystalline form to form the matrix of the undissolved shells, etc.[3]

Mr. Bailey Willis has recently studied the question of the deposition of carbonate of lime, and states that "chemists describe two conditions under which bicarbonate of lime may be decomposed into neutral carbonate and carbonic acid: 1st, by diminution of the tension of the carbonic acid in the atmosphere; 2nd, by agitation of the solution."

[1] Loc. cit., p. 255.

[2] Loc. cit., p. 277. In this connection I wish to ask the student to read Messrs. Murray and Irvine's remarks on pp. 97-99, Proc. Roy. Soc., Edinburgh, Vol. 17, 1890.

[3] Proc. Roy. Soc., Edinburgh, Vol. 17, 1890, pp. 94-95.

"Theoretically either one of three things may occur to the neutral carbonate of lime, if it be thrown out of solution by either one of these processes. The carbonate may be redissolved, deposited as a calcareous mud, or built into organic structure." He studied some recent limestone deposited in the Everglades of southern Florida and found it to be formed of fragments of shells embedded in calcite. He states that, "Under the microscope the unaltered structure of the organic fragments is strikingly different from that of the coarse holocrystalline matrix, in which it is apparent that the crystals developed in place. Were this a limestone of some past geologic period it would be concluded, on the evidence of the crystalline texture of some parts of it, that it had been metamorphosed, and that the organic remains now visible had escaped the process which altered the matrix. But the observed conditions of its formation preclude the hypothesis of secondary crystallization."[1] Apparently the crystalline matrix is one primary product, and the calcareous mud is another, which being precipitated in the solution remains an incoherent sediment.

I think we may accept the conclusion that the deposition of carbonate of lime is by both organic agency and chemical precipitation. It is not necessary to speak of deposition by mechanical methods except in relation to the deposition of chemically derived granules. This probably takes place, and may be a very important factor in the formation of limestones in seas receiving a large supply of calcium from the land. Calcareous conglomerates do not enter as a prominent deposit in the Cordilleran area.

There is no evidence in the marine, geologic formations of this continent that they were deposited in the deep sea; on the contrary they are unlike such deposits and bear positive evidence of having been laid down in relatively shallow waters. Limestones with ripple-marks and sun cracks occur, and beds of ripple-marked sandstones alternate with shales and limestones. The more massive limestones, however, appear to have accumulated in deeper water. The conditions in the Cordilleran sea

[1] See Mr. Willis' article in Journal of Geology, Chicago, September, 1893.

were, I think, more favorable for rapid deposition than in the deep open ocean, but probably not as favorable as about coral reefs and islands. The limestones, and often the contained fossils, clearly indicate the presence of many of the same conditions of deposition as described by the authors I have quoted. More or less decomposed shells occur in nearly every limestone and a large proportion of limestone; especially the non-metamorphic marbles clearly show that they were deposited under the influence of the agencies at work in the laboratory of the sea. Willis states that this occurs in the shallow waters of the Everglades of Florida, and there is no *a priori* reason why it did not occur throughout geologic time,—on the contrary, there is no doubt that it did.

Rate of deposit in former times.—It has frequently been assumed that in the earlier epochs the conditions were more favorable for rapid denudation, and in consequence thereof the transportation and deposition of sediment was greater. Professor Prestwich considers [1] that prior to the sedimentary rocks the land surface consisted of crystalline or igneous rocks subject to rapid decomposition owing to the composition of the atmosphere and to their inherent tendency to decay. They must have yielded to wear and removal with a facility unknown amongst mechanically formed and detrital strata where erosion operates. He thus accounts for one of the factors that gave the large dimensions and thicknesses of the earlier formations. Mr. Wallace thinks that geological change was probably greater in very remote times,[2] stating that all tellurac action increases as we go back into the past time, and that all the forces that have brought about geological phenomena were greater.[3]

[1] Geology, Vol. 1, 1886, pp. 60-61.

[2] Island Life, 2nd Ed., 1892, pp. 223-224.

[3] Sir William Thompson (Lord Kelvin), inferred from his investigations upon the cooling of the earth, that the general climate cannot be sensibly affected by conducted heat at any time more than 10,000 years after the commencement of the superficial solidification. Treatise on Natural Philosophy, Cambridge, 1883, Vol. 1, pt. 2, p. 478. Of the degree of the sun's heat we know so little that conjectures in relation to it have little force against the conditions indicated by the sedimentary rocks and their contained organic remains.

Dr. Woodward says, on the opposite view, that in the earliest geological periods each bed of sand, clay, limestone, etc., had actually to be formed, and that later deposits had the older sedimentary ones to furnish material, and, therefore, the newer deposits were laid down more rapidly.[1] This does not impress me strongly; but from my experience among the Paleozoic rocks I agree with Sir A. Geikie, that "We can see no proof whatever, nor ever any evidence which suggests that on the whole the rate of waste and sedimentation was more rapid during Mesozoic and Paleozoic time than it is to-day.[2]

Professor Huxley, in his presidential address to the Geological Society of London in 1870, treats of the distribution of animals and says of his hypothesis that it "requires no supposition that the rate of change in organic life has been either greater or less in ancient times than it is now; nor any assumption, either physical or biological, which has not its justification in analogous phenomena of existing nature."[3]

In the Grand Cañon of the Colorado, Arizona, there are 11,950 feet of strata of Algonkian age extending unconformably beneath the Cambrian. There is nothing in this section to indicate that the conditions of deposition were unlike those of the strata of Paleozoic and Mesozoic time. The sandstones, shales, and limestones are identical in appearance and characteristics with those of the latter epoch. The deposition of sulphate of lime and gypsum occurred abundantly in the upper portions of the series, and salt is collected by the Indians from the deposits formed by the saline waters issuing from the sandstone 8,000 feet below the summit of the series. The sandstone and shales were deposited in thin, even laminæ and layers, and the sun cracks and ripple marks give evidence of slow, uniform deposition. In the upper part of Chuar terrane there are 235 feet of limestone. And in one of the layers of limestone, 2,700 feet below the summit of the Chuar terrane, I find abundant evidence of the pres-

[1] Geol. England and Wales, 2nd Ed., 1887, p. 23.

[2] Rept. Sixty-second Meeting Brit. Assoc. Adv. Sci., 1892, p. 19.

[3] Quart. Jour. Geol. Soc., Vol. 26, 1870, p. lxiii.

ence of spiculæ of sponges, and what appear to be worn fragments of some small fossils. There is absolutely nothing to indicate more rapid denudation and corresponding deposition in this early pre-Cambrian series than we find in the Paleozoic, Mesozoic or Cenozoic formations.

PALEOZOIC SEDIMENTS OF THE CORDILLERAN SEA.

The great sections of sedimentary rocks in Arizona, Nevada, Utah, Montana, and in Alberta, B. A., all bear evidence that the sediments of which they are built up were deposited in a connected and continuous sea that extended from the vicinity of the 34th parallel, on the south, to the Arctic ocean on the north. Judging from the data now available, the width of this sea varied from 300 miles in Nevada to 500 miles on the line of the 40th parallel, and, with interruptions by mountain ridges, to 250 miles on the 49th parallel. It appears to have narrowed to the north in Alberta, British Columbia. Roughly computed, it covered south of the 55th parallel 400,000 square miles exclusive of any extension westward into northern-central California and southwestern Oregon and to the eastward over the area subsequently covered by the great interior Cretaceous sea. There is also an addition that might be made to allow for the contraction of the area by the later north-and-south faults and thrusts. Dr. G. M. Dawson estimates that in the Alberta and British Columbia area the width of the zone of the Paleozoic rocks has probably been reduced one-half by the folding and faulting, or from 200 to 100 miles.[1] This area assumed for the Cordilleran sea is on this account probably one-half less than it was before the Appalachian revolution.

The Wasatch section, on the eastern side of the area under consideration, has 30,000 feet of strata, of which 10,400 feet are limestone.[2] Further to the west, 250 miles W.S.W., at Eureka, Nevada, there 30,000 feet of strata in the entire section, and of this amount 19,000 feet are referred to limestone.[3] In the Pahranagat range and vicinity, 200 miles south of the Eureka section,[4]

[1] Bull. Geol. Soc. Am., Vol. 2, 1891, p. 176.

[2] Geol. Expl. Fortieth Parallel, Vol. 1, 1878, pp. 155-156.

[3] Mon. U. S. Geol. Survey, Vol. 20, 1892, p. 178.

[4] Loc. cit. pp. 186-200.

the limestones of the Paleozoic measure over 13,000 feet in a section of 13,500 feet. This section includes only 350 feet of the upper beds of the lower quartzite series, which is upwards of 11,000 feet in thickness in the Schell Creek range of eastern Nevada.[1]

On the eastern side of the area, in Montana, 300 miles north of the Wasatch section of Utah, the deposit of Paleozoic sediment is less in volume. Dr. A. C. Peale's section gives 3,800 feet of limestone in 5,000 feet of strata.[2] This does not include the 6,000 feet or more of sediments that occur below the fossiliferous Cambrian. I believe that the Paleozoic section will be found to be considerably thicker to the westward in Idaho. Continuing to the north 450 miles, the sections measured by Mr. R. G. McConnell, give 29,000 feet of Paleozoic strata, including 14,000 feet of limestone[3]. In a "Note on the Geological Structure of the Selkirk Range," Dr. Geo. M. Dawson describes a section containing upwards of 40,000 feet of mechanical sediments, which he refers largely to the Cambrian[4].

The Paleozoic limestones extend to the north, on the line of the eastern Rocky Mountains, to the Arctic ocean. In latitude 55° to 60° N. the Devonian limestones are over 2,500 feet in thickness, and there other still lower Paleozoic rocks that have not yet been studied in detail. The Devonian limestones extend 700 miles in the valley of the Mackenzie, from Great Slave Lake to below Fort Good Hope.[5] No Carboniferous limestones have been described from this region.

Tabulating the sections south from the 55th parallel and allowing for a great thinning out of the sediments in Idaho and Montana, we obtain an approximate general average of 21,000 feet of strata, of which 6,000 feet are limestone over an area estimated to include 400,000 square miles. Each square mile

[1] Geol. and Geog. Surveys West of 100th Merid., Vol. 3; Geology, 1875, p. 167.

[2] Author's manuscript.

[3] Geol. and Nat. Hist. Sur. Canada; Am. Rep., 1866, pp. 17, D–30 D.

[4] Bull. Geo. Soc. Am. Vol. 2, 1891, p. 168.

[5] Rept. Expl. Yukon and Mackenzie Rivers Basins, N. W. Terr. Geolo. & Nat. Hist. Sur. Canada, Vol. 4 (1888–'89), 1890, pp. 13 D–18 D.

includes 27,878,400 cubic feet of limestone for each foot in thickness and 167,270,400,000 cubic feet for a thickness of 6,000 feet, which, with an average of 12.5 cubic feet to ton, gives 13,381,632,000 tons of limestone and impurities per square mile. The result of ten analyses of clear limestones within the central portion of area gives an average of 76.5 per cent. of carbonate of lime.[1] Taking 75 per cent. as the proportion of pure carbonate of lime (after deducting 50 per cent. to allow for arenaceous and argillaceous material in partings of strata, etc.), there remain 5,018,112,000 tons per square mile; multiplying this by 400,000 the result gives the number of tons of carbonate of lime that were deposited in what we know of the Cordilleran sea in Paleozoic time, or 2,007,244,800,000,000 tons, or two billion million tons in round numbers.

The following mode of presentation of the above was suggested by Mr. Willis:

In order to proceed with a calculation of the period required to form this thickness of 15,000 feet of mechanical sediment plus 6,000 feet of calcareous sediment, it is necessary, 1st, to compute the cubic volumes of the sediments; 2d, to estimate the area from which they were derived; and, 3d, to divide the cubic contents of the sediments by this land area. The result thus obtained represents the depth of erosion required to furnish the whole deposit, from which we may estimate the time under different assumptions of the rate of erosion.

But if we express amounts in cubic feet or tons the figures pass all comprehension; therefore, to simplify the statement, it is well to use a mile-foot as the unit of volume, that is, the volume of one mile square and one foot thick. (1 mile-foot=.79 Kilometre-metres). This is equal to 223,000 tons, if 12½ cubic feet of limestone equal one ton.

Thus stated mechanical sediments covering 400,000 square miles and 15,000 feet thick contain 6 billion mile-feet (4,740 million Kilometre-metres); and calcareous sediments covering the same area and 6,000 feet thick correspond to 2 billion 4 hundred million mile-feet (1,896 million Kilometre-metres). In the calcareous sediments a liberal allowance of one-half may be made for arenaceous and argillaceous matter in the limestone and partings, and analyses of ten clear limestones within the central part of the area give a little more than 75 per cent. of carbonate of lime. Applying these reductions we get 900 million mile feet (711 million Kilometre-metres) of pure carbonate of lime.

DURATION OF PALEOZOIC TIME IN THE CORDILLERAN AREA.

Estimates from Mechanical Sedimentation.—The land area tributary to the Cordilleran sea was larger before the depression of

[1] Geol. Expl. Fortieth Par. Vol. 2; Mon. U. S. Geol. Survey, Vol. 20.

the continent, towards the close of middle Cambrian time than during subsequent Paleozoic time. It included a portion of the region to the eastward and probably a belt of land extending well towards the Pacific coast of the continental-plateau. The interior (Mississippian) region, west of the 90th meridian, probably drained into the sea to the south, forming a Cambrian Mississippi river prior to middle Cambrian time. This limits the Cambrian drainage into the Cordilleran sea to an area estimated at 1,600,000 square miles. The average thickness of mechanical sediments deposited before upper Cambrian time is estimated at from 10,000 to 15,000 feet. Taking the minimum of 10,000 feet and the assumed drainage area of 1,600,000 square miles and the rate of denudation at one foot in 1,000 years, it would have required 2,500,000 years to carry to the sea and distribute the 10,000 feet of sediment. This means the deposition of .048 of an inch per year, which is very small if the supposed conditions of denudation and transportation were as favorable as the character and mode of occurrence of the sediments indicate. If one-fourth of an inch per year is assumed as the rate of deposition, the 10,000 feet of sediment would have accumulated in 480,000 years or, in round numbers, in 500,000 years, which increases the rate of denudation to one foot in 200 years.[1]

CAMBRIAN MECHANICAL SEDIMENTS.

Rate of erosion over land area of 1,600,000 square miles.	Time in years for erosion of 2,500 feet.	Rate of deposition over sea area of 400,000 square miles for strata 10,000 feet thick.
1 foot in 3,000 years, - -	7,500,000	1 foot in 750 years, or .016 inch per annum.
1 foot in 1,000 years, - -	2,500,000	1 foot in 250 years, or .048 inch per annum.
1 foot in 200 years - - -	500,000	1 foot in 50 years, or .24 inch per annum.

In view of the evidence of rapid accumulation contained in the strata themselves the most rapid rate of deposition here stated, namely, .24 inch per annum, is considered as the most probable.

[1] By Mr. Willis' method (*ante*, p. 662, foot note) the mechanical sediments of the Paleozoic age for the area under consideration corresponds to 6 billion mile-feet.

In dealing with the post-middle Cambrian mechanical sediments we have a somewhat different problem, but, as a whole, rapid deposition is indicated. For instance, the Eureka quartzite of the upper Ordovician is a bed of sandstone, varying from 200 to 400 feet in thickness, distributed over a wide area,—perhaps 50,000 square miles. It is made almost entirely of a white, clean sand that was deposited in so short an interval that the Trenton fauna in the limestone beneath it and in the limestones above it is essentially the same. The sand appears to have been swept rapidly into the sea and distributed by strong currents. The same is true of the 3,000 feet of the lower Carboniferous sand and the 2,000 feet in the upper portion of the Carboniferous, while the shales of the upper Devonian accumulated more slowly. In this connection we must bear in mind that during the long periods in which the calcareous sediments forming the limestones were being deposited, the tributary land areas were in all probability base-levels of erosion, and chemical denudation was preparing a great supply of mechanical material that, on the raising of the land, was rapidly swept into the sea and distributed. In this manner the time period of actual mechanical denudation was materially shortened, yet, on account of the manifestly slower deposition of the Devonian shales, the rate of denudation should be assumed as less than during Cambrian time.

In post-Cambrian time the area of the land surface was materially reduced by subsidence, which did not, however, greatly extend the Cordilleran sea, and it may fairly be estimated at 600,000 square miles. The depth of mechanical sediments already estimated is 5,000 feet, and their volume at two billion mile-feet. Dividing the volume by the area of erosion we get 3,300 feet as the depth of erosion required.

Again, applying different rates of erosion, with allowance for slow progress of degradation during Devonian time, we have:

Of this total the greater part, namely, two-thirds or 4 billion mile-feet, are of Cambrian age. Dividing this volume by the land area just given, 1,600,000 square miles, we get 2,500 feet as the depth of erosion during the formation of the Cambrian mechanical sediments. Assuming different rates of erosion we may obtain times differing as follows:

POST-CAMBRIAN MECHANICAL SEDIMENTS.

Rate of erosion over land area of 600,000 square miles.	Time required for removal of 3,300 feet.	Rate of deposition in sea of 400,000 square miles, for 5,000 feet of strata.
1 foot in 3,000 years, - -	9,900,000 years	1 foot in 1,980 years, or .006 inch per annum.
1 foot in 1,000 years, - -	3,300,000 years	1 foot in 660 years, or .09 inch per annum.
1 foot in 200 years, - - -	660,000 years	1 foot in 132 years, or .18 inch per annum.

The rate of one foot in 200 years is assumed as the most probable and 660,000 years as the time required for the removal and deposition of the 5,000 feet of post-Cambrian mechanical sediments.

There is one factor that may need to be taken into consideration in estimating the time duration of the deposition of the mechanical sediments of the Cambrian and pre-Cambrian of the northern portion of the Cordilleran sea that would materially lengthen the period. Dr. George M. Dawson describes the Nisconlith series, especially in the Selkirk range of British Columbia, as composed of "blackish argillite-schists and phyllites, generally calcareous, with some beds of limestone and quartzite, 15,000 feet."[1] It is correlated with the Bow River series, which contains, in the upper portion, the lower Cambrian fauna. The presence of these calcareous beds indicates a slower rate of deposition than we have estimated for the lower portion of the Cambrian series over the greater part of the Cordilleran sea; but as yet the correlation with the sediments of the Cordileran sea is not sufficiently well established to warrant our allowing a greater time period to the Cambrian on this account.

Estimates from Chemical Sedimentation.—We have estimated that the Paleozoic sediments of the Cordilleran sea contain 2,007,244,800 million tons (900 million mile-feet) of carbonate of lime, which was derived by organic or chemical agencies from the sea water to which it was contributed by the land. If oceanic circulation could be excluded from the problem we might pro-

[1] Bull. Geol. Soc. Amer., Vol. II., 1891, p. 168.

ceed directly to estimate the time required to obtain this amount of lime from the land area tributary to the Cordilleran sea. It may be well to make such an estimate on the basis that the area of denudation tributary to the Cordilleran sea in post-middle Cambrian time had 600,000 square miles from which 30,000,000 tons of carbonate of lime and 12,000,000 tons of sulphate of lime were derived per annum,[1] if we assume T. Mellard Reade's rate of erosion—of 50 tons of carbonate of lime and 20 tons of sulphate of lime per square mile per annum. If all of the 42,000,000 tons (equal to 18.8 mile-feet) per annum were deposited within the limits of the Cordilleran sea, it would have taken 47,790,000 years for the accumulation of the carbonate of lime now estimated to have been deposited in the Cordilleran sea. Such a result is manifestly a maximum based on the consideration of one set of phenomena. In addition, however, to this supply of calcium the geographic conditions appear to have been favorable to the free circulation of oceanic currents through the Cordilleran sea, and the temperature was favorable to extensive evaporation and to the development of organic life, as shown by the occurrence of corals in the middle and upper portions of the Paleozoic, from the Mackenzie river basin on the north to southern Nevada on the south. These conditions would reduce the time necessary for the deposition of the carbonate line.

Ocean water of the present time contains in solution 151.025000 tons of solid matter per cubic mile, which is divided among various salts. A comparison of the matter in the sea and river water shows that the sea contains 3.85 parts of magnesium to one of calcium, and river water contains three parts of calcium to one of magnesium. The silica and alumina of the river water disappears in sea water, while the sodium is accumulated. It is from these considerations and the fact that limestones are

[1] Messrs. Murray and Renard consider that organisms have the power of secreting the carbonate of lime from the sulphate of lime contained in the sea water by chemical reaction. For an account of the chemical action that takes place in the sea water, see report of the Deep-Sea Deposits of the Challenger Expedition.

so largely formed of carbonate of lime that I have taken the latter as a basis for estimates upon the rate of chemical sedimentation, an allowance being made for the presence of silica, alumina and magnesium in the limestones.

Rate of Deposition of Recent Deposits.—Of the rate of deposition in recent deposits Messrs. Murray and Renard state, in their report on the deep-sea deposits, that: "It must be admitted that at the present time we have no definite knowledge as to the absolute rate of accumulation of any deep-sea deposit, although we have some information and some indications as to the relative rate of accumulation of the different types of deposits among themselves. The most rapid accumulation appears to take place in the Terrigenous Deposits, and especially in the Blue Muds, not far removed from the embouchures of large rivers. Here no great time would seem to have elapsed since the deposit was formed, so far at least as the materials collected by the dredge, trawl, and sounding tube are concerned.

"Around some coral reefs the accumulation must be rapid, for, although pelagic species with calcareous shells may be numerous in the surface waters, it is often impossible to detect more than an occasional pelagic shell among the other calcareous debris of the deposits.

"The Pelagic Deposits as a whole, having regard to the nature and condition of their organic and mineralogical constituents, evidently accumulate at a much slower rate than the terrigenous deposits, in which the materials washed down from the land play so large a part. The Pteropod and Globigerina oozes of the tropical regions, being chiefly made up of the calcareous shells of a much larger number of tropical species, must necessarily accumulate at greater rate than the Globigerina oozes in extra-tropical areas or other organic oozes. Diatom ooze, being composed of both calcareous and siliceous organisms, has, again, a more rapid rate of deposition than the Radiolarian ooze, while in a Red Clay there is a minimum rate of growth." [1]

[1] Report on the scientific results of the voyage of H. M. S. Challenger; Deep-Sea Deposits. 1891, pp. 411-412.

Professor James D. Dana estimates that the rate of increase of coral reef limestone formations, where all is most favorable, does not exceed perhaps a sixteenth of an inch in a year, or five feet in a thousand years. Of this he says, "And yet such limestones probably form at a more rapid rate than those made of shells."[1]

Messrs. Murray and Irvine, in their valuable paper on coral reefs and other carbonate of lime formations in modern seas, calculate the total amount of calcium in the whole ocean to be 628,340,000 million tons; also they estimate that 925,866,500 tons of calcium are carried into the ocean from all the rivers of the globe annually. At this rate it would take 680,000 years for the river drainage from the land to carry down an amount of calcium equal to that at present existing in solution in the whole ocean. They say further: "Again, taking the 'Challenger' deposits as a guide, the amount of calcium in these deposits, if they be 22 feet thick, is equal to the total amount of calcium in solution in the whole ocean at the present time. It follows from this that, if the salinity of the ocean has remained the same as at present during the whole of this period, then it has taken 680,000 years for the deposits of the above thickness, or containing calcium in amount equal to that at present in solution in the ocean, to have accumulated on the floor of the ocean."[2] According to this calculation the mean rate of accumulation over existing oceanic areas is $\frac{22}{680000}$. or .000032 feet per annum.

Was the Deposition of Chemical Sediment More Rapid in Paleozoic Time?—It has been claimed that the quantity of lime poured into the ocean in earlier times was greater than during the later epochs of geological history,—this arising from the more rapid disintegration of the Archean, crystalline and volcanic rocks. It is undoubtedly a fact that the ocean was stocked in Archean and Algonkian time with matter in solution that produced salinity, but we have no evidence from chemical precipitation that more

[1] Corals and Coral Islands, 3rd Ed., 1890, pp. 396-397.

[2] Proc. Royal Soc., Edinburgh, Vol. 17, 1890, p. 101.

calcium was poured into it than could be retained in solution. The Laurentian limestones are crystalline, but, as has been shown, this texture is consistent with either chemical or organic origin. The unaltered limestones in the Algonkian rocks of the Colorado Cañon section show traces of life in thin sections, and they may be, to a great extent, of organic origin. There is no evidence in the texture, bedding or composition of these ancient limestones to indicate that they were deposited under conditions of salinity or of supply differing materially from those of the present, and I do not find that we have reason to believe that the deposition of the carbonate of lime was more rapid in the Paleozoic than during the Mesozoic and Cenozoic times, even though the supply from the land may have been greater. Where the conditions were favorable for the deposition of lime, as in the Cretaceous sea of northern Mexico, we find evidence of an immense accumulation of calcareous sediments. Of the amount of calcareous deposits in the seas outside of the continental areas that are not open to our inspection, we know nothing; but judging from the deposition that is going on to-day in the great oceans, the accumulation of calcareous sediment has gone on in the past as steadily and uninterruptedly as at present, subject to varying conditions of temperature, life, depth of water, etc.

Area of Deposition in Paleozoic Time.—We have no proof that the salinity of the sea or the amount of calcium contained in it has varied from age to age since Algonkian time. If it has not, all of the calcium poured into the ocean during 2,000,000 years would have about equaled the amount now contained in the limestones of that area. We have, however, to account for the calcium deposited in the interior Mississippian sea and the seas over other portions of this continent and other continental areas, and on portions of the floor of the ocean that are now accessible for observation. It is also to be considered that the land areas subject to denudation in Paleozoic time were, in all probability, of no larger extent than at the present time.

The area of dry land to-day is estimated to be 55,000,000 square miles, and of oceans 137,200,000 square miles.[1]

Mr. T. Mellard Reade estimates the area of the Paleozoic formations of Europe at 645,600 square miles in the total area of 3,720,500 square miles. His estimate of the Paleozoic area is of that which is exposed at the present time, and does not include that which is concealed beneath other formations. I think it will be a minimum estimate to consider that an equal area is covered by the later formations, which, with that exposed, would give in round numbers 1,290,000 square miles,—or one-third of the land area of Europe. In North America nearly one-half of the total area was covered by the Paleozoic sea; in South America it was considerably less; and we know too little of the Asiatic and African continents to place any estimate upon their Paleozoic areas. I think, however, if we take one-fourth of the present land area as the territory covered by the Paleozoic seas we shall be considerably within the actual amount, even if we add to the surface of the continents the margins of the continental platforms now beneath the sea. Deducting the one-fourth from the total land area, there remain 41,250,000 square miles as the land area undergoing denudation during Paleozoic time. It may be claimed that large areas in the archipelago region of the Pacific and in the Arctic ocean may have been land areas at that time. To meet this, 8,750,000 square miles may be added to the 41,250,000, giving a total of 50,000,000 square miles as the land area of Paleozoic time.

The estimated areas of the various deep sea deposits of to-day, containing a large percentage of the carbonate of lime, are as follows: Globigerina ooze, 49,520,000 square miles, mean percentage of carbonate of lime, 64.53; Pteropod ooze, 400,000 square miles, percentage of carbonate of lime, 79.26; Coral mud and sand, 2,556,000 square miles, mean percentage of carbonate of lime, 86.41. In addition to this, Diatom ooze covers an area of 10,880,000 square miles, with 22.96 percentage of carbonate of lime; and the mean percentage of carbonate of lime in the

[1] Dr. JOHN MURRAY: Scottish Geog. Mag., Vol. 4, 1888, p. 40.

Blue Mud and other terrigenous deposits that cover 16,050,000 square miles is 19.20. If we consider only those deposits containing over 64 per cent. of carbonate of lime, we have 52,500,000 square miles, over which there is at the present time a deposition of the carbonate of lime being made. We have roughly estimated that in Paleozoic time the area of the Paleozoic sea, in which deposits were being accumulated, was over 13,000,000 square miles. It does not appear that there is any good reason to suspect that the area of deposition of the carbonate of lime in the open ocean during Paleozoic time was not fully equal to that of the present time. Adding this area of 52,500,000 to the 13,750,000, we have over 66,000,000 square miles as the probable area in which calcium was being deposited in Paleozoic time.

Conditions favorable for a rapid deposition of the carbonate of lime.—The condition most favorable for the rapid accumulation or deposition of the carbonate of lime through organic or mechanical agency is warm water and a constant supply of water through circulation by currents; this is shown by the immense abundance of life where the margin of the continental plateau is touched by the Gulf Stream. Another favorable condition is the supply of carbonate of lime by river water directly into the ocean in the vicinity where the deposition of lime is going on either through organic or inorganic agencies. This is well illustrated by the conditions produced by the Gulf Stream. The oceanic currents, passing along the northeastern coast of South America, sweep the waters of the Amazon through the Caribbean sea into the Gulf of Mexico, where they meet the vast volume of water coming from the Mississippi. These are poured out through the narrow straits between Florida and Cuba and carried northward over the sloping margin of the continental plateau. Under such favorable conditions the deposit must be much greater than in areas where there is little circulation and the supply of calcium is limited to the average which is contained in sea water. If to the preceding there is added extensive evaporation within a partially enclosed sea, the rate of deposition of matter in solution will be largely increased.

The area over which calcareous depositions was going on during Paleozoic time we have estimated at 66,000,000 square miles, which includes the areas of the seas over the continental platforms and those of the surrounding oceans. As the conditions appear to have been more favorable for the deposition of lime in the Cordilleran aud Appalachian seas, we will assume that it was four times that of the open ocean.[1] With a land area of 50,000,000 square miles (*ante* p. 670) and a rate of chemical denudation of 70 tons per square mile per annum, the total calcium contributed to the ocean per year during Paleozoic time would be 3,500 million tons or 3.78 times as much as that estimated for per annum at the present time, which is 925,866,-500 tons (*ante* p. 668). This would have provided 50.7 tons for deposition per annum per square mile in the 65,000,000 square miles of ocean and seas and 202.8 tons for deposition per annum per square mile in the 400,000 square miles of the Cordilleran and 600,000 square miles of similar seas. On this basis 81,120,000 tons (36.4 mile-feet) were contributed per annum from the ocean water to the deposit in the Cordilleran sea; adding to this the 42,000,000 tons (18.8 mile-feet) contributed per annum by the denudation of the surrounding area to the Cordilleran sea, we have 128,120,000 tons (55.2 mile-feet) as the amount available for deposit per annum in the Cordilleran sea. At this rate it would have required 16,300,000 years to have deposited the 2,007,244,800 million tons (900 million mile-feet) of *calcium* in the Cordilleran sea; adding to this the 1,200,000 years estimated for the deposition of the mechanical sediments, we have a total of 17,500,000 years as the duration of Paleozoic time.

In reviewing the preceding estimates we must consider that,

[1] Under the reduction of 50 per cent. for the interbedded and intermingled mechanical sediments and 25 per cent. for other material than calcium deposited from solution, the apparent amount of calcium deposited in the Cordilleran sea was greatly reduced. If this same ratio of reduction is applied to other Paleozoic limestone areas, I doubt if over 1,000,000 square miles will be found to contain as large an average amount of calcium per square mile as the Cordilleran area. On this account 1,000,000 square miles is the area taken for the greater rate of deposition of calcium during Paleozoic time.

throughout, I have increased the various factors above those usually accepted: thus, for mechanical sedimentation, one foot in 200 years is used. If the usually accepted average of one foot in 3,000 years is taken the time period must be increased fifteenfold (21,000,000 years), or the area of denudation from 1,600,000 square miles to 24,000,000—or three times the present area of the North American continent.

In the estimate for the amount of chemical denudation the largest average is taken—70 tons of calcium per square mile per annum—and the assumption made that all calcium derived from the adjoining drainage was deposited within the Cordilleran sea. Again, the total supply provided per annum to ocean waters of Paleozoic time is taken as 3.78 times greater than the amount annually contributed to ocean waters to-day; of this, four times as much is assumed to have been taken out per annum per square mile as was taken by the remaining area in which calcium was being deposited.

The area of the Cordilleran sea is given as 400,000 square miles, but it was probably 600,000, if not much more. It may be claimed that the area tributary to the Cordilleran sea was greater than I have estimated. The evidence, such as it is, is against such a view. As a whole I think the estimate of 17,500,000 years for the duration of Paleozoic time in the Cordilleran area is below the minimum rather than above it.

If the estimated rate of the deposition of coral limestones—five feet in 1,000 years—given by Prof. Jas. D. Dana is correct, the 19,000 feet of Paleozoic limestone in central Nevada would have required 3,800,000 years to have accumulated under the most favorable local conditions surrounding a coral reef. With the exception of large deposits of corals in Devonian rocks no appearance of a coral reef is recorded in the Cordilleran area.

TIME-RATIOS OF GEOLOGIC PERIODS.

The time-ratio adopted by Prof. James D. Dana for the Paleozoic, Mesozoic and Cenozoic periods is: 12, 3, and 1, respectively[1]. Prof. Henry S. Williams applies the term *geochronology*,

[1] Manual of Geology, 1875, p. 586.

giving the standard time-unit used the name *geochrone*. The geochrone used by him in obtaining a standard scale of geochronology is the period represented by the Eocene. His time-scale gives 15 for the Paleozoic; 3 for the Mesozoic; and 1 for the Cenozoic, including the Quaternary and the Recent.[1]

The Rev. Samuel Haughton obtained the following time-ratios from the maximum thickness of strata as they occur in Europe:

SCALE OF GEOLOGICAL TIME.

Period.	From Theory of Cooling Globe.	From Maximum Thickness of Strata.
Azoic	33.0 per cent.	34.3 per cent.
Paleozoic	41.0 "	42.5 "
Neozoic	26.0 "	23.2 "
Total	100.0 per cent.	100.0 per cent.

He draws from this the principle—"*The proper relative measure of geological periods is the maximum thickness of the strata formed during these periods.*"[2]

In considering the time-ratios for the Paleozoic, Mesozoic, and Cenozoic rocks of the North American continent, as given by Dana and Williams, I think that a too small proportion has been given to the Mesozoic and Cenozoic. In the Mesozoic of the western-central area occur the coal deposits of the Laramie series and the great development of limestone (from 10,000 to 20,000 feet) in the Cretaceous of Mexico. The limits of this paper do not permit of a discussion of the available data bearing upon geologic time-ratios; but from a comparison of the Paleozoic, Mesozoic, and Cenozoic strata and the geologic phenomena accompanying their deposition, I would increase the comparative length of the Mesozoic and Cenozoic periods so that the time-ratios would be: Paleozoic, 12; Mesozoic, 5; Cenozoic, including Pleistocene, 2.

DURATION OF POST-ARCHEAN GEOLOGIC TIME.

Taking as a basis 17,500,000 years for Paleozoic time and the time-ratios, 12, 5, and 2 for Paleozoic, Mesozoic, and Ceno-

[1] Journal of Geology, Chicago, Vol. I., 1893, pp. 294-295.

[2] Nature, Vol. 18, 1878, p. 268.

zoic (including Pleistocene) respectively, the Mesozoic is given a time duration of 7,240,000 years, the Cenozoic of 2,900,000 years, and the entire series of fossiliferous sedimentary rocks of 27,650,000 years. To this there is to be added the period in which all of the sediments were deposited between the basal crystalline Archean complex and the base of the Paleozoic. Notwithstanding the immense accumulation of mechanical sediments in this Algonkian time, with their great unconformities and the great differentiation of life at the beginning of Paleozoic time, I am not willing with our present information to assign a greater time period than that of the Paleozoic—or 17,500,000 years. Even this seems excessive. Adding to it the time period of the fossiliferous sedimentary rocks, the result is 45,150,000 years for post-Archean time. Of the duration of Archean or pre-Algonkian time, I have no estimate based on a study of Archean strata to offer. If we assume Haughton's estimate of 33 per cent. for the Azoic period and 67 per cent. for the sedimentary rocks, Archean time would be represented by the period of 22,250,000 years. In estimating for the Archean, Haughton included a large series of strata that are now placed in the Algonkian of the Proterozoic of the United States Geological Survey; and I think that his estimate is more than one-half too large; if so, ten million years would be a fair estimate, or rather conjecture, for Archean time.

Period.	Time Duration.
Cenozoic, including Pleistocene	2,900,000 years
Mesozoic	7,240,000 "
Paleozoic	17,500,000 "
Algonkian	17,500,000 "
Archean	10,000,000(?)"

It is easy to vary these results by assuming different values for area and rate of denudation, the rate of deposition of carbonate of lime, etc.; but there remains, after each attempt I have made that was based on any reliable facts of thickness, extent and character of strata, a result that does not pass below 25,000,000 to 30,000,000 years as a minimum and 60,000,000 to

70,000,000 years as a maximum for post-Archean Geologic time. I have not referred to the rate of development of life, as that is virtually controlled by conditions of environment.

In conclusion, geologic time is of great but not of indefinite duration. I believe that it can be measured by tens of millions, but not by single millions or hundreds of millions of years.

CHARLES D. WALCOTT.

ON THE ORIGIN OF THE PENNSYLVANIA ANTHRACITE.[1]

Long ago, H. D. Rogers showed that the coal regions of Pennsylvania are divided into rudely longitudinal basins or troughs. In passing over the state northwestwardly, one crosses first the Archean area at the southeast, with its patches of Newark or Triassic; then the Great Valley, extending almost unbroken from the Hudson river to Alabama, and showing only Cambrian and Silurian with occasional patches of Devonian and Lower Carboniferous. Crossing the irregular northerly or northwesterly boundary of the valley, he reaches what, for the purpose of this discussion, may be termed the Anthracite Strip, which extends to the Alleghanies; this contains the Cumberland coal field of West Virginia and Maryland, the Broad Top field of southern Pennsylvania, and, still further northeast, the Southern, Middle and Northern Anthracite fields. The Bituminous coal basins, of which Rogers recognized six, are beyond the Alleghanies; the first, between the Alleghanies and Laurel Hill, is well defined near the Maryland line, but becomes less so northward, though it can be traced without difficulty into New York; the second, with Chestnut Hill as its westerly boundary, is the Ligonier Valley, which like the last can be followed into New York; the third, wider than the second, is less defined at the west, as its boundary on that side is an anticline passing but a little way east from Pittsburgh and producing insignificant topographical effects; the most important portion of the basin, in this connection, is the first sub-basin, known as the Connellsville coke basin, which follows the westerly foot of Chestnut Hill. The remaining bituminous basins, including the rest of

[1] Abstract of a paper read before the Geological Society of America, August, 1893.

Pennsylvania, northwestern West Virginia and eastern Ohio may be regarded as one, their details being unimportant in so far as the present study is concerned.

The trend of the anticlinal and synclinal axes is not N. N. E. and S. S. W. throughout, for one of the great curves of the Appalachian system is within Pennsylvania; the axis of the First Bituminous basin, for example, follows an almost W. S. W. direction until, in Clearfield county, midway in the state, its course is changed to S. S. W.; any topographical map of Pennsylvania illustrates the condition.

Interesting variations in the rate of dip are shown along a line drawn from Pittsburgh, Pa., southeastwardly across the coal area to the Cumberland field in Maryland, the contrast between the terminal conditions being very great. At Pittsburgh, the rate seldom exceeds one degree; in the Connellsville sub-basin it varies from four or six degrees along the lower portion of the trough to somewhat more than ten degrees on the side of Chestnut Hill, the increase in rate thus far being quite regular. No further increase is found in crossing the second and first basins, the dip even on the easterly side of the Alleghanies rarely exceeding twelve degrees. But the extent of disturbance becomes markedly greater at once after the Anthracite Strip has been reached, for there dips of 20, 40, 70 and 80 degrees are seen.

The conditions observed along this line are not representative of those throughout the coal area, for in all the basins, even in those of the Anthracite Strip, the degree of disturbance eventually becomes less along the trend northwardly. The existence of the anthracite fields themselves is due to a remarkable decrease in violence of the disturbance, a dying away northward of anticlines, permitting formation of broad synclines, which in their turn act as do the canoe synclines of the bituminous areas, which, rising, send the lower formations into the air. Southwardly, the condition is markedly different; for though the extent of disturbance, except in the Anthracite Strip, decreases rapidly, the decrease is due to depression of anticlines and not,

as at the north, to the general elevation of the synclines and their passage into the New York plateau.

Analyses of coal samples, taken from the Pittsburgh bed in the several basins, show a progressive decrease in the proportion of volatile, combustible matter toward the east or southeast, a fact which early attracted the attention of H. D. Rogers, and which has possessed much interest for geologists ever since. Analyses made for the Second Pennsylvania Survey prove the same condition in the lower coals. Mr. Winslow's studies of the Arkansas coals show a similar tendency to decrease in the same direction; and Murchison discovered a like condition in the Donetz anthracite field of southern Russia.

H. D. Rogers,[1] in 1842, announced to the Association of American Geologists the law of gradation, as he understood it, which involves "a progressive increase in the proportion of the volatile matter, passing from a nearly total deficiency of it in the driest anthracites to an ample abundance in the richest caking coal." Finding, as he believed, that the volatile matter in the coal augments westwardly, precisely as the flexures diminish, he attributed the variation to the influence of steam and other intensely heated gases escaping through crevices necessarily produced during the permanent bending of the strata. Under such conditions, the coal throughout the eastern basins, the more disturbed, would discharge more or less of the volatile constituents during the violent earthquake action, whereas the more western beds, less disturbed, would be less debituminized.

J. J. Stevenson,[2] in 1877, showed that the variations in volatile exhibited by the Pittsburgh coal bed along the southeast and northwest line bear no relation whatever to increase or decrease of stratigraphical disturbance, and suggested that the variations are due to difference of conditions under which the coal was formed.

[1] ROGERS: Reps. of the 1st, 2d and 3rd meetings of the Association of American Geologists and Naturalists. 1843, pp. 470 et seq.

[2] STEVENSON: 2d Geol. Surv. of Penn., Rep. of Progress on the Fayette and Westmoreland Dist. Pt. I. pp. 61, et seq.

J. P. Lesley,[1] in 1879, offered some interesting suggestions. If the anthracite be metamorphosed bituminous coal, the change might be caused by exposure to comparatively high temperature at a great depth below the surface. As the temperature increases one degree Fahrenheit for each fifty feet, more or less, of descent, the coal under cover of a great thickness of rock could not fail to be deprived of its volatile matter. He compares the composition of coal from the highest available bed in western Pennsylvania with that from the lowest bed in the same region, and finds less volatile in that from the lower bed. As all of the Paleozoic rocks thicken eastwardly, there must have been a much greater pile of Coal Measures in the anthracite region than in the bituminous areas, though erosion has removed the proof. Necessarily then the coals of the anthracite region should show less volatile than do those of the bituminous area, where the pile of rocks was less thick.

Professor Lesley suggests also that if one desire to explain the origin of the anthracite by oxidation in preference to metamorphism, the conditions afford basis for such explanation, since in the anthracite region the rocks are not only broken and shattered by the folding, but they are made up largely of sand and gravel, so that the conditions are such as to favor percolation of water, evaporation, and consequently oxidation; whereas, in the undisturbed bituminous areas, clayey beds are in large proportion and lute down the buried coals so as to prevent percolation and the rest.

There is no possible room for doubt that bituminous coal can be converted into anthracite by heat. The Galisteo, Elk Mountain and other localities within the United States, the Hesse Cassel and New Zealand areas in foreign lands, prove beyond dispute that, under proper conditions, contact with molten rocks suffices for the conversion. But no question of such conversion is at issue here, for in Pennsylvania no dikes occur near enough to the anthracite areas, or large enough even if near enough, to

[1] LESLEY: In McCreath, 2d Geol. Surv. of Penn., 2d Rep. of Progress in the Laboratory, etc. 1879, pp. 153, et seq.

produce by contact the extensive tracts of anthracite still remaining in the state.

Professor Rogers's explanation seems to have been based throughout on a misunderstanding of the conditions. There is no good reason for supposing that the Appalachian Revolution was produced by violent disturbances such as those imagined by Professor Rogers; on the contrary, there appear to be the best of reasons for supposing the final folding to be but an acceleration of the process which had gone on, perhaps not continuously, from a very early period. The slowness of the process even at the close is suggested by the courses of the main waterways. The fundamental error, however, respects the relation of dip and volatile. The dip along the line selected by Professor Rogers, that from Pittsburgh to the Cumberland coal field in Maryland, does indeed show great changes, but as already stated they are not gradual. Let the condition be recalled. At Pittsburgh, the dip is from $\frac{1}{2}°$ to $1°$; in the Coke basin, 30 miles away, it is from $4°-6°$ at the lower portion of the trough, to $10°-12°$ higher up the side of the anticline; in the Salisbury basin, 34 miles further, the dip is the same or less, there being practically no change in the interval from the Coke basin; and no further change is found until one has passed the Alleghanies and entered the Anthracite Strip, where a marvelous change is seen, for the dip is sometimes vertical. Now despite all this, the decrease in volatile, as shown by the Pittsburgh coal bed along this line, is almost regular; thus at Pittsburgh, the average analysis shows of volatile 40.7 per cent. (ash and water being ignored in the calculation); at Connellsville, 33.8, a decrease of 6.9 in 30 miles with an increase of dip from $1°$ to say $8°$; at Salisbury, the volatile is only 23.3, a decrease in 34 miles of 10.5 with no change whatever in rate or type of folding; while in the Cumberland basin, about 15 miles further, the volatile is 18.8, a decrease of only 4.5, despite the complete change in type and remarkable increase in extent of disturbance; and this last field is within the anthracite strip itself, is in proper position, along the trend, to be the continuation of the Northern Anthracite field.

Professor Rogers's error in this matter prevented him from observing that the volatile decreases northwardly along the trend in the several basins even more notably than along the line chosen by him. The hardest anthracite is not in the Southern field, where the folding is most complicated, but in the Eastern Middle. The Southern Anthracite field shows all gradations from bituminous coal at its southern extremity to hard, dry anthracite at its northerly end.

Professor Lesley's suggestion that the Coal Measures attained to much greater thickness in the anthracite region than in the bituminous areas hardly accords with the facts as now known, many of them published since he offered his suggestions. It is altogether certain now that the lower three divisions of the Coal Measures in Pennsylvania, the Pottsville, the Lower Coal Group and the Lower Barren Group, do not show any variations which would justify one in basing a theory upon them; and it is much more than probable that the Upper Coal Group and the Permo-Carboniferous attain their greatest thickness in the north central portion of the Appalachian basin, and that they diminish in thickness westwardly, northwardly and eastwardly from southwestern Pennsylvania, as abundantly appears from the measurements made by I. C. White and by the writer in Pennsylvania, Ohio and West Virginia. In any event, the thickness of the mass in northeastern Pennsylvania was small in comparison with the thickness of the series in Virginia, West Virginia and Kentucky, on the southeastern edge of the Appalachian basin; yet in those states the coal shows no tendency to be anthracite; that of the Imboden coal bed of Virginia and Kentucky, almost at the base of the Lower Coal Group of Pennsylvania, is richly bituminous.

Nor does the theory that anthracite is bituminous coal converted by heat due to mechanical force, commend itself in this connection. The crushed and polished coal of the Broad Top field is bituminous, whereas the uncrushed coal of the Northern field in the same strip is anthracite. The Quinnimont coal, in the gently flexed New River district of West Virginia, has

practically the same amount of volatile as is found in the same coal near Pocahontas, Virginia, close to the great fault of Abbs valley.

But it is unnecessary to look to metamorphism for an explanation of the Pennsylvania anthracite; at best, metamorphism is an unsatisfactory explanation, because it is difficult to find evidence that metamorphosing agencies have been in operation there. One does not think of metamorphism when he finds in the coal of a given bed a variation of five or ten per cent. of volatile within short distances, or even when he finds, as in Sullivan county of Pennsylvania, anthracite in one bench and bituminous in another bench at the same opening.

As was shown long ago by Bischof and others, anthracite can be produced simply by continuation of the process whereby vegetable matter is converted into bituminous coal—by continued formation of carburetted hydrogen until the hydrogen has been removed. Professor Lesley's ingenious suggestion that this can go on more readily in the anthracite region than in the bituminous areas, because of the difference in composition and condition of the rocks, hardly suffices. If only the extremes of the series were to be accounted for, and if all were confined to the anthracite strip, it might be regarded as sufficient; but all gradations from rich caking coal to anthracite occur in the First bituminous basin, where the rocks are comparatively undisturbed and consist largely of argillaceous shale. Moreover, in a single colliery within the Southern Anthracite field, one bench of the Mammoth bed yields a more than semi-bituminous coal, while from another is obtained almost the driest of anthracite. But an equally serious objection is, that the coal must have been converted finally before complete entombment, so that the effect of the pressure would be to remove water and to solidify the coal. The hardening of the coal was complete in the Broad Top field before the Appalachian revolution occurred, for in the final folding the coal, as shown in some mines, was broken into lenticular and polished fragments precisely like those of the Utica shale within the disturbed valley east from the Anthracite Strip. The Lara-

mie coals on the western side of the great plains in New Mexico, Colorado and Wyoming can hardly have undergone any material change since the final burial; otherwise the strange variations in composition would be inexplicable, the difference in condition as to character of rocks and degree of disturbance being insufficient.

Twenty years ago the writer, while connected with the Ohio Survey, reached the conclusion that the marsh, from which sprang the several beds of the Upper Coal group, originated at the east; two years later he was led to assert that the coal beds were formed as fringes along the shore of the Appalachian basin. If this be the true doctrine, there should be found in northeastern Pennsylvania,

First. A vastly greater thickness of coal than in other portions of the basin.

Second. A greater advance in the conversion of vegetable matter into coal, owing to the longer period elapsing prior to entombment.

As to the first condition, there can be no doubt. A comparison of the several divisions of the Coal Measures as they appear in the several basins of the state illustrates it well; but such a comparison would be tedious here, and only the Lower Coal group of the Pennsylvania series is used (that lying between the Pottsville conglomerate below and the Mahoning sandstone above).

In the Anthracite Strip this group shows in the several fields, from south to north, as follows:

Cumberland Field, bituminous, - - -	13′
Broad Top Field, bituminous, - - -	14′–15′
Southern Anthracite, bituminous to anthracite, -	18′–60′
Middle and Northern Anthracite, anthracite, -	40′–58′

The thicknesses in the Bituminous basins are:

First, - - - - - -	21′–23′
Second, - - - - - -	19′–22′
Fifth, - - - - -	8′6″–13′4″

The thicknesses, as given for the Anthracite Strip, are those

of coal exclusive of slate and other partings, but those for the Bituminous areas include the slates and other partings, so that the actual amount of coal is less than the figures indicate. It is sufficiently clear that the conditions favoring the accumulation of coal in beds continued longer without interruption in the anthracite region than they did elsewhere within the Appalachian basin; for the contrast is equally marked, when the anthracite region is compared with the Virginias or Kentucky further southwestward. The process of conversion also continued longer without interruption, as the chemical analyses show.[1] Thus, in the Anthracite Strip, one finds:

Cumberland Field (only the Pittsburgh),	4.47– 4.78	Coal, 13′
Broad Top Field, - - -	3.26– 4.64	Coal, 14′
Southern Anthracite Field,		
Southern prong, - -	4.36–12.40	Coal, 18′–30′
Main Field, - - -	11.64–23.27	Coal, 30′–60′
Western Middle Field, -	19.87–24	Coal, 40′–58′
Eastern Middle Field, - -	25.53–30.35	Coal, 52′–53′
Northern Field, - -	19.37–19.92	Coal, 44′–53′

The anthracite analyses are commercial, samples chosen from carload lots. Very much higher ratios are obtained by sampling single benches.

The First and Second Bituminous basins show a similar change along the line of trend, the amount of volatile decreasing northwardly as one approaches the old shore line.[2] Thus, in the First, the Clarion coal bed shows from 2.94 to 4.84 near the Maryland line, but from 7.07 to 10.28 in Sullivan county, where is its last exposure at the north. In the Second basin, the Upper Freeport coal shows 2.26 to 2.85 near the Maryland border, but 3.96 to 4.48 at the last northerly exposure, in Lycoming county. The variations in the Third and other basins are less, as one

[1] The figures here given are the ratios between the Fixed Carbon and the Volatile Combustible, the ash and water being ignored; the more volatile, the smaller the ratio.

[2] Some curious variations, apparently contradictory of the statement here made, occur in the analyses. These will be discussed and their interest shown by the writer in a review of theories respecting the origin of coal beds, which is now in course of preparation.

should expect, for according to the supposition, the conditions at that distance from the old shore line should vary little anywhere.

So one finds,

First. A decided increase in thickness of coal eastward, or better, northeastward toward the anthracite region, and a less marked increase northward in the Bituminous basins.

Second. A decided decrease in volatile in the direction of increased thickness of coal, the decrease being comparatively gradual until near the anthracite fields.

Third. That this decrease is gradual even in the Anthracite Strip from the Cumberland Field to the semi-bituminous coals of the Southern Anthracite field, where the rapid increase in thickness is accompanied by a rapid decrease in the volatile.

When, in 1877, the writer called the attention of his colleagues on the Pennsylvania Survey to the fact that the decrease in volatile is wholly without relation to increase or decrease of disturbance in the strata, he suggested that the variation was due to difference in conditions under which the coal had been formed in the several localities discussed—a sufficiently comprehensive hypothesis, but yielding in this respect to some others of later date. Now, however, there seems to be no good reason for any such suggestion; all that was needed was longer exposure to the process whereby ordinary bituminous coal was formed. In origin, the anthracite coal of Pennsylvania differs in no wise from the bituminous coal of other parts of the Appalachian basin; but because the great marsh, from which sprang the many beds, originated in the northeastern corner of the basin and extended thence again and again on the advancing deltas formed by streams descending from the Appalachian highlands, the time during which the successive portions of the marsh would be exposed would be less and less as the distance from the northeastern and northern border of the basin increased, so that the extent of chemical change would decrease as the distance increased. It is, therefore, to be expected that in the northeastern corner, where the deltas were formed quickly after subsidence was checked, and

beyond which they advanced slowly, as shown by changing type of rocks, the chemical change should have been almost complete, especially in the eastern Middle and the eastern extremity of the Southern field, which occupy that part of the area in which the coal marsh, in almost every instance, appears to have thrust itself first upon the advancing delta.

It is quite possible that when detailed study of the anthracite areas in Arkansas and Russia have been made, the same explanation may be found applicable there also, and that the anthracite will be found near the old shore line, whence the marsh advanced as new land was formed. JOHN J. STEVENSON.

THE BASIC MASSIVE ROCKS OF THE LAKE SUPERIOR REGION.

III. THE GREAT GABBRO MASS OF NORTH-EASTERN MINNESOTA.[1]

A. Introduction.

As HAS already been stated in an earlier paper,[2] the writer purposes, as time and opportunity permit, to discuss the petrographical and stratigraphical relationships of the basic rocks that constitute such an important element in the geology of the country bordering Lake Superior. In the series of papers, of which this is the first, the petrographical characteristics of the various types of these rocks will be described, and the views held by previous workers with respect to their geological relationships will be outlined. Thus, it is hoped, a foundation will be laid for a new and more thorough investigation of the field relations of these rocks than has heretofore been possible. As the case now stands, several of the geologists who have investigated the eruptive rocks of this region have erred in confusing types of entirely different origins, and have thereby introduced into the literature errors of observation that have rendered a clear understanding of the Lake Superior geology almost impossible.

When practicable the laboratory and field study of rocks should proceed together, each aiding the other in solving the knotty problems that so often arise in their progress. The laboratory study of the eruptives in the region under consideration has been almost entirely neglected, and consequently the field problems arising in connection with them have largely remained unsolved. When the peculiarities of these rocks—their composition and structure—become known, much light will be thrown upon their nature, and it will then be time to again review their field relations, when it is believed that many

[1] This Journal, Vol. I., pp. 433 and 587.

[2] This Journal, Vol. I., p. 435.

of the difficulties now surrounding them will disappear. At present the main results reached by the field-geologists who have busied themselves with the rocks under discussion will be referred to. They must pass unchallenged except in the few cases where the microscopic evidence is directly at variance with them; and when there is no field evidence directly substantiating them. At some time in the near future it is hoped that an opportunity will offer itself for a more detailed study of the rocks in the field. Then it will be proper to criticise the conclusions arrived at by previous workers, and to suggest new views as to the position and relation of the eruptives with respect to the rocks with which they are associated.

B. The Position of the Gabbro.

The great gabbro mass which is the subject of this paper has been placed by Irving in the Keweenawan group, the separation of which from the underlying Huronian slates and quartzites and the overlying Cambrian sandstone, is due principally to the investigations of Brooks, Pumpelly, Irving and Chamberlin. The history of the discussion which has led to the recognition of the great Keweenawan series it will not be necessary to outline, as it is well given in the essays, whose authors have been named.[1]

The only detailed description of the series as a whole has been given us by Irving,[2] who makes it "include only the suc-

[1] It should be stated here that although the individuality of the copper-bearing series of rocks is recognized by nearly all geologists who have worked in the Lake Superior region, several have declined to regard it as a distinct series, equivalent to the Huronian or the Cambrian. These geologists prefer to look upon it as belonging with the latter group as its lower member. Dr. Wadsworth has long held this view, and Prof. N. H. Winchell (8th Ann. Rept. Geol. and Nat. Hist. Survey of Minn., p. 22; 17th ibid., pp. 54-55) in one of his most recent reports sums up the work of the Minnesota Survey in this direction in the statement that the Keweenawan series is closely linked with "the great gabbro flow," to which reference will be made hereafter, and that both are members of the Potsdam. In a later report (20th Ann. Rept. Geol. and Nat. Hist. Survey of Minn., p. 3) the same writer discusses the age of the gabbro and concludes that it is much older than the Potsdam, but he does not assert positively that the Keeweenawan beds overlying it are pre-Cambrian.

[2] The Copper-Bearing Rocks of Lake Superior, R. D. Irving: Monograph V., U. S. Geol. Survey, Washington, 1883.

cession of interbedded 'traps,' amygdaloids, felsitic porphyries, porphyry-conglomerates, and sandstones, and the conformably overlying thick sandstones, as typically developed in the region of Keweenaw Point and Portage Lake on the south shore of Lake Superior."[1]

Although no distinct line of division between them can be pointed out, the beds of the series naturally fall into an upper division made up wholly of detrital material, principally shales and red sandstones, and a lower division consisting chiefly of a succession of basic flows, layers of conglomerate and sandstone and quite a large proportion of flows of acid eruptive rocks. The thickness of the upper division is estimated at 15,000 feet at its greatest, and that of the lower division at from 22,000 to 24,000 feet.

The recent discovery that the central part of the Keweenawan is underlain unconformably by a great mass of anorthosite, which along the middle portion of the Minnesota coast comes to the surface in many places, suggests to Lawson[2] that the maximum thickness of the lower Keweenawan beds at this place must be much less than Irving's estimate. His own figures are only about one-tenth those of Irving. VanHise[3] in a review of Lawson's article takes exception to the author's small estimate, and prefers to accept Irving's figures, until these are proven inaccurate by careful detailed investigation of the problem in the field.

Since it is only in the lower division that eruptive rocks occur, our attention will be confined entirely to this. It is not possible to determine positively for the entire series the actual succession of the subordinate members belonging in it, for this, in an eruptive series, may vary in different areas, but Irving believes that the following "broad horizons" may be recognized: (1) a succession of heavily bedded coarse-grained olivine and orthoclase gabbros, forming the base of the series; (2) a series of olivine diabases and diabase-porphyrites, occurring at the lower hori-

[1] l. c., p. 24.

[2] Geol. and Nat. Hist. Survey of Minn., Bull. No. 8, p. 21.

[3] Jour. of Geology, Vol. I., p. 312.

zons, together with acid eruptives of all kinds common to the group, as quartz-porphyries, quartzless-porphyries, and fine-grained red granites; (3) olivine-free diabases and other basic rocks with amygdaloidal upper and lower surfaces; and (4) detrital beds, chiefly porphyry conglomerates and sandstones, rare in the lower third of the series, but increasing in thickness and frequency towards the top. These various subordinate divisions have been separated into smaller sub-divisions, and their sequence, where possible, has been carefully detailed, but since a discussion of this classification is not necessary to our present purpose it need not be entered upon.

The lowest of the divisions of rocks belonging in Irving's Keweenawan has been said to consist of a succession of heavily bedded coarse-grained olivine and orthoclase gabbros. The best exhibition of these gabbros is found in north-eastern Minnesota, where the area underlain by them occupies about 2100 miles of the surface of the state, extending from the east line of Range 1, E., to about the middle of Range 15, W. The general shape of the area is crescentic with the concave side turned toward Lake Superior and its convex side facing the north-west. In its widest part the crescent measures about twenty-two miles from south-east to north-west. The chord connecting its two horns is about 125 miles in length. The eastern extremity forms a narrow point about three miles north-west of Greenwood Lake, from which point the area extends westward, widening gradually until it reaches its broadest expanse, and then gradually contracting until it finally abuts against the north shore of St. Louis Bay west of Duluth, where it appears as a band forming the shore line for ten or twelve miles, beginning in the western portion of the city of Duluth and ending four miles east of Fond du Lac.

A second[1] area of basal gabbro is in the Bad River region in Wisconsin. Here the rock forms a narrow belt about forty-eight miles in length and from two to five miles in width, stretching from the Gogogashugun river south-westward to near Numakagon lake, in T. 43 N., R. 6 W., Wis.

[1] Cf. pl. XXII., Copper-Bearing Rocks.

It was not until a few years since that an attempt was made to discover the true relations of these gabbros to the surrounding rocks. In his Copper-Bearing Rocks (p. 266) Prof. Irving places them at the base of the Keweenawan group, at the same time stating that "There is no definite evidence of unconformity between the gabbros and the slates of the Saint Louis River," regarded as Animikie. In a later paper the same writer[1] refers to a coarse-grained, stratiform olivine-gabbro at the base of the Keweenawan.

Though nowhere so stated, the olivine-gabbros had by this time been separated by the author from the overlying "orthoclase gabbros," and had been placed by him at the very base of the Keweenawan group, with the orthoclase-gabbros immediately above them. In his article[2] on the classification of the early Cambrian and pre-Cambrian formations, we have this description of the position and nature of this great mass of rocks, ". . . . We find at the base of the series [Keweenawan] an immense development of stratiform, fresh and often exceedingly coarse olivine-gabbro, the individual layers of which, notwithstanding their complete crystallization, very coarse grain, and lack of amygdaloidal or dense upper surfaces, seem evidently to have formed great flows at the surface of the region as it stood at the time of their extrusion."

No more explicit statements of his views concerning this basal gabbro appear in any of Irving's writings. A reference to the geological map of north-eastern Minnesota accompanying the paper last referred to, will, however, show that at this time (1886) he believed the basal gabbro in Minnesota to rest unconformably upon the Animikie, since the former is represented as cutting transversely belts of St. Louis slates, the Mesabi granite and schists of the Archean, and the eastern area of Animikie slates along the boundary line between Minnesota and Canada, which slates here strike nearly east and west.

Although in his maps the "gabbro flow" is represented as

[1] Am. Jour. Sci., 3d ser., vol. 34, 1887, pp. 204, 249.

[2] Seventh Ann. Rept. U. S. Geol. Survey, 1888, p. 419.

belonging with the Keweenawan rocks, the Wisconsin mass was nevertheless recognized by Irving as presenting "the appearance of a certain sort of unconformity with the overlying beds. These gabbros, which lie immediately upon the Huronian slates, form a belt which tapers out rapidly at both ends, and seems to lie right in the course of the diabase belts to the east and west, since these belts, both westward toward Lake Numakagon, and eastward toward the Montreal river, lie directly against the older rocks, without any of the coarse gabbro intervening." . . . "The great extent of coarse gabbro in Minnesota seems to sustain somewhat the same relations to more regularly bedded portions of the series." [1]

The only other descriptions of this great gabbro mass are to be found in the reports of the Minnesota survey. In the report for 1887 Prof. N. H. Winchell[2] details a few of his observations on the "great gabbro flood," and surmises that the "flow" did not escape through a single fissure. The structure of the rock is reported as roughly columnar, with sometimes apparent indications "of the existence of imbricating layers having a gentle dip, as if the fluid rock had swept over the country in successive tides. . . . In texture the gabbro is characteristically coarse. Sometimes some of the constituent minerals are half an inch in diameter. From this they graduate down to an extreme degree of fineness."

From the macroscopic descriptions of other varieties of the rock that follow it is evident that the writer is not dealing exclusively with specimens taken from the great "gabbro flood" at the base of the Keweenawan, for, as the sequel will show, this is composed of a rock which, in its unaltered state, possesses a remarkably uniform texture, and is so well characterized that any departure from it is presumptive evidence that the rock exhibiting the variation belongs not in the "basal flow," but in some one of the numerous smaller beds interstratified with the Animi-

[1] Copper-Bearing Rocks, p. 155.

[2] Geol. and Nat. Hist. Survey of Minnesota, 16th Ann. Rept. for 1887. St. Paul, 1888, pp. 360-362.

kie and the Keweenawan strata at various horizons, or in some one of the many dykes cutting these.

In the report[1] of the following year, upon referring to the position of the gabbro with respect to the other formations, Prof. Winchell says . . . "In general the gabbro lies on the Animikie (Taconic) in Minnesota." At Chub (Akeley) lake, however, it seems to be underlain by a bed of quartzite, regarded as a lower member of the copper-bearing formation of the Potsdam (Keweenawan of Irving and Chamberlin) in the seventeenth report, but looked upon as Animikie and denominated the Pewabic quartzite in the sixteenth report,[2] and described under the field name "muscovado" in earlier reports.

In a more recent discussion[3] as to the age of the gabbro, Prof. Winchell briefly summarizes his previous views on the subject, and concludes that the supposed quartzite underlying the gabbro belongs near the bottom of the Animikie, and since the eruptive rock is so closely associated with the fragmental one, that the former must be of nearly the same age as the latter.[4]

This conclusion is based on the supposition that the rocks immediately underlying the gabbro are fragmental quartzites that have been altered by the eruptive for miles even from its contact with them.[5] But this is probably not always the case. As the writer[6] has shown in another place, some of the so-called quartzites are very basic crystalline aggregates of pyroxene and olivine, and others are granulitic phases of the overlying gabbro. Since they are portions of the gabbro they are of the same age as this, and are not available as stratigraphical data for use in determining the time relations of the great "flow" with respect

[1] 17th Ann. Rept. for 1888. St. Paul, 1891, p. 52.

[2] 16th Ann. Rept., pp. 82-87.

[3] The Iron Ores of Minnesota. Bull. Minn. Geol. Survey, No. 6, 1891, p. 125.

[4] Cf. also: 20th Ann. Report, p. 2.

[5] H. V. WINCHELL: Ib. p. 127.

[6] BAYLEY W. S.: Notes on the Petrography and Geology of the Akeley Lake Region in Northeastern Minnesota. 19th Ann. Rept. Minn. Survey. Minneapolis, 1892, p. 193 et seq.

to the Animikie and the Keweenawan rocks. Some of the rocks, called by Winchell Pewabic quartzite, are probably true Animikie fragmentals, or metamorphosed phases of these, but even in this case there is no proof that the gabbro immediately succeeds them in point of age. The evidence would simply indicate that the eruptive is younger than the Animikie. It would not fix its age more definitely. The observations of Winchell would thus seem to lead to the same conclusion as that reached by Irving in so far as the latter supposed the gabbro to be post-Huronian.

Upon returning again to the problem as to the age of the gabbro Winchell [1] attempts to fix this more definitely by assuming the identity of this rock with the anorthosite, which is shown by Lawson to be older than the bedded Keweenawan. But it is impossible at present to assert with any degree of certainty, that the two rocks are the same (although VanHise holds with Winchell that their equivalency is possible), for the one has not been traced into the other, nor has the upper limit of the gabbro been carefully studied. This great mass may be much older than the lowermost beds of the Keweenawan series, but as yet there has been cited no proof in favor of the view.

So far as the little evidence at hand enables us to judge, the gabbro whose petrographical characteristics are discussed in this article, forms a great mass of enormous extent above the Animikie but below the interbedded flows and fragmentals of the Keweenawan series in Minnesota. There are obscure indications that the mass is a great layer composed of successive flows that followed one another so rapidly as to give no opportunity for the action of erosion processes or for deposition between them. If this be so the lack of more apparent bedding is doubtless due to the great thickness of the individual beds, as is also their coarse grain. There are some things about the mass, however, that suggest another origin for it. "The great coarseness of grain, the perfection of the crystallization, the abrupt termination of the belts, the complete want of structure, and the presence of intersecting areas of crystalline granitoid rocks — all suggest the

[1] Bull. No. 8. Geol. and Nat. Hist. Survey of Minn. p. xviii.

possibility that we have here to do with masses which have solidified at great depths. They certainly cannot, however, be regarded as intrusive in the ordinary sense of the word; so that, unless we regard them as great outflows, we should be forced to look upon them as the now solidified reservoirs from which the ordinary Keweenawan flows have come."[1]

C. Petrographical Description of the Normal Phase of the Gabbro.

Up to the present time there has appeared no general petrographic description of the great gabbro supposed to be at the base of the Keweenawan, although both Irving and Wadsworth have given detailed descriptions of hand specimens taken from it. The former writer,[2] in his monograph on the copper-bearing rocks, refers to the great mass at Duluth as consisting principally of a coarse orthoclase gabbro, but including some orthoclase-free gabbro. The rock is "massive and irregularly jointed, making great ledges facing in different directions, and furnishing bare rounded summits to the hills which it composes."

"The prevalent type of the gabbro . . . is of a light gray color, and very coarse-grained, single feldspar crystals sometimes reaching even an inch or two in length. The augitic ingredient is plainly in greatly subordinate quantity, and often on a fresh surface its presence cannot be detected at all. On exposed surfaces, however, the weathering generally brings it out, and then it can be plainly seen to fill the spaces between the feldspars. Titaniferous magnetite is also often perceptible to the naked eye in large particles."

"Less commonly the grain is finer and the color darker, the augitic ingredient at the same time becoming more plentiful. In the thin section the predominant feldspar is seen to be a plagioclase belonging near the oligoclase end of the series. There appears also to be a younger feldspar present, which has the character of orthoclase and fills corners between the plagioclase crystals, around whose contours it moulds itself sharply. Streng and

[1] Copper-Bearing Rocks, p. 144.

[2] Copper-Bearing Rocks, Mon. V., U. S. Geol. Survey, p. 266 and 269.

Kloos[1] found 1.61 per cent of potash in the rock, which they very properly regarded as belonging to orthoclase. The spaces between the feldspars are filled with a diallage which is always more or less altered to greenish uralite. The alteration in many sections is carried beyond uralite to chlorite. The magnetite is very large, abundant and titaniferous. Apatites of large size are found in all sections. Biotite is not an uncommon accessory. Olivine is absent from all sections."

It is very evident that the writer is not describing by these words the rock of the great 'flow' as he defined it in his later papers, but that he is dealing exclusively with the orthoclase gabbros, which were afterwards separated from the underlying mass and given a position just above this.[2]

The only specimen of the true basal gabbro examined by Irving[3] came from the Cloquet river, in Sec. 34, T. 53 N., R. 14 W. in Minnesota. This he characterizes as "A very fresh olivine-gabbro. It is light gray in color, very coarse grained, and [is] composed chiefly of very fresh plagioclase (anorthite). Quite fresh diallage fills in the space between the feldspars. A few large fresh olivines occur here and there in the section. Titaniferous magnetite is abundant, and large sized, and biotite occurs in a few small scales."

Dr. Wadsworth[4] made no attempt to describe the general features of this great mass of rock. His descriptions are of hand specimens furnished him for examination by the officers of the Minnesota survey. Among them were several representatives of the "basal flow,"[5] but these were not studied with reference to each other, except in regard to their alterations.

[1] Neues Jahrb. f. Min., etc., 1877, p. 113.

[2] See ante, p. 692.

[3] Copper-Bearing Rocks, p. 272, also p. 46.

[4] Geol. and Nat. Hist. Survey of Minnesota. Bull. No. 2.

[5] The specimens described by Dr. Wadsworth that are thought to belong to the basal gabbro are the following: No. 696, p. 69; 706 and 702, p. 70; 773 and 713, p. 71; 699, 769 and 701, p. 72; 689 and 721, p. 75; 780, p. 85; 707, p. 87; 693, p. 88; 694, 704 and 703, p. 89; 787, p. 90; 715, 692 and 777, p. 91; 691, p. 92; 700, 714 and 698, p. 93; 705, p. 94; 514 and 513, p. 95; 697 and 776, p. 96; and 781, p. 97.

It has already been intimated that the normal rock of the great gabbro is so uniform in its general character that, after studying carefully one of its hand specimens, others might easily be identified among a collection of specimens of the basic rocks of the Lake Superior region, without much danger of error. Its description, therefore, is quite a simple matter. In its macroscopic aspect the normal rock is a medium to coarse-grained, gray, granular aggregate of a very lustrous plagioclase and a black augite. The plagioclase is usually more abundant than the darker mineral; its dimensions are larger, and its contours more frequently approximate to those of crystals. It is of a light gray color and has a glassy lustre on fresh fractures, while on weathered surfaces it is white and opaque. Twinning striations are visible on nearly every grain. The augite on the contrary is jet black. Its cleavage faces are rather small, and its contours never approach those of crystals; they are occasionally triangular or wedge-shaped when they have any definite form, but are usually very irregular in outline. In some of the coarse-grained varieties of the rock there is a rudely lamellar arrangement of both the augite and the feldspar, so that the mass possesses a platy structure. With this exception the gabbro has the typical granitic texture, and is thus easily distinguished from all the other so-called flow gabbros of northeastern Minnesota and the region bordering on Lake Superior in which is more or less perfectly developed the diabasic texture.

The principal varietal differences noted in the rock are due solely to the proportions of feldspar, augite and olivine present in it. When the pyroxene is in moderate quantity the appearance of the specimen is as indicated above. Sometimes the feldspar is largely in excess, and pyroxene has almost entirely disappeared. Now the rock has a lighter gray color, and the bright shining black particles are lacking. Again olivine is the principal component when the tint of the rock becomes dark green. The structure in all cases, however, remains the same. The varieties are merely local phases of the predominant rock for on all sides they grade into one another by insensible transitions. The

density of the varieties depends of course upon their composition ; the larger the proportion of feldspar present the lower the specific gravity. Of the three specimens whose densities were determined, one (10440) was found to have a specific gravity of 2.8061, another (8786) of 2.9475, and the third (8589) of 3.0636.

The sections of nearly all specimens taken from the interior of the gabbro area, or from points at some little distance from its northern edge are similar, in that they represent a very fresh rock, whose structure is monotonous and whose composition is quite simple. All contain magnetite, olivine, pyroxene and plagioclase as primary constituents, and many have in addition as secondary components, biotite, chlorite and quartz. The proportions of secondary products present are never sufficiently large to affect the characteristics of the rock as a whole, though they be abundant enough to change materially its appearance in thin section. The usual succession in the formation of the primary minerals is as indicated, and in this respect does the gabbro of the mass under discussion differ most essentially from the other "gabbros" of the same and neighboring regions, for in all of the latter rocks studied the pyroxene is younger than the plagioclase.

The feldspar is the most abundant of the essential components, sometimes constituting, as it does, almost the entire section. It is nearly always in large grains, whose contours are very irregular in shape, and only very rarely resemble those of the lath-shaped grains of diabasic plagioclase. The mineral is quite fresh and is devoid of secondary inclusions, other than a few flakes of kaolin and small flecks of some chloritic substance. The characteristic acicular inclusions of gabbroitic feldspar are sometimes absent from the plagioclase of the Minnesota rock, but more frequently they are present in the usual forms. Small areas of augite and little grains of biotite and magnetite are also enclosed in the feldspar, and dust-like particles are scattered everywhere throughout the grain. The inclusion of augite within the plagioclase would seem to show that the latter mineral is undoubtedly younger than the former; but certain triangular areas of pyroxene between grains of plagioclase would point to

the opposite conclusion. The amount of plagioclase in all portions of the gabbro mass is so great that it must have occupied a long period in its separation. It is probable that the augite began to separate from the magma that yielded the rock some time before the plagioclase, but that after the feldspar began to crystallize the two minerals grew side by side until all the pyroxenic material of the magma had been extracted from it, when the feldspar continued its growth unaccompanied by the formation of pyroxene. Thus some of the plagioclase is older than some of the augite, though the greater part is younger than the great mass of this mineral.

All the plagioclase grains are traversed by broad twinning lamellæ, the maximum extinction on each side of whose composition plane is about 35°. In order to determine accurately the nature of this plagioclase, the three specimens whose densities are given, were powdered and their feldspars separated by the Thoulet solution. Most of the mineral was precipitated when the density of the solution was between 2.674 and 2.728, the limits in the different cases being as follows: in specimen 8786 between 2.700 and 2.728; in 8589 between 2.700 and 2.711, and in 10440 between 2.674 and 2.712. As a small amount of the plagioclase in each specimen was more or less altered, the average of the above figures may be taken as representing the average density of the plagioclase in the gabbro. The method is justified in the fact that the optical properties of the powder in all cases was exactly the same, and that its precipitation was not in steps or stages, but was continuous between the limits mentioned. The mean density of the feldspar separated from the three rocks was thus 2.701, which indicates a very basic labradorite. In the feldspar of a specimen of the gabbro from the Cloquet river Irving[1] reports 52.40 per cent. of SiO_2, while for the most acid member of the bytownite series Tschermak[2] calculates 49.1 per cent. of SiO_2. The largest quantities of the powder in the above three cases fell respectively at 2.700, 2.711 and 2.712.

[1] Copper-Bearing Rocks, p. 439.

[2] Lehrb. d. Mineralogie, 2te Aufl. 1885, p. 439.

There can thus be no doubt that the feldspar throughout the entire mass of the rock is practically of the same character, since the three specimens tested were taken from three widely separated portions of the gabbro area, and each represents a distinct type of the rock. No. 8786 is very rich in olivine, No. 8589 contains much augite and a large quantity of brown biotite, while No. 10440 is very rich in feldspar and quite poor in pyroxene.

An analysis of the feldspar separated from No. 8786, and partial analyses of the plagioclase from the other rocks were made by Dr. W. H. Hillebrand. They are as follows:

	8786	8589	10440a	10440b
SiO_2	51.89	52.18	47.59	46.92
Al_2O_3	29.68	29.20	30.97	31.51
Fe_2O_3	.32	1.11	1.55*	1.29*
FeO	.37			
CaO	12.62	11.18		
MgO	.38			
K_2O	.50			
Na_2O	3.87			
H_2O (100°)	.07			
H_2O (above 100°)	.39			
Total	100.09			
Sp. Gr.	2.700	2.711	2.712	2.674

The figures under 8786 and 8589 correspond very closely with those of a basic labradorite. Those under 10440a and 10440b are abnormal, in that they indicate that the more basic portion of the feldspar in this rock has a lower specific gravity than the more acid one. The alumina in the four cases, however, corresponds quite well with the proportion of this oxide in basic labradorites. In Ab_1An_3, which Tschermak makes the dividing line between labradorite and bytownite, the percentage of alumina present is 32.8 per cent. Since the rock specimens from which these feldspars were separated represent the only phases of the gabbro that have retained the normal gabbro characteristics, it is probable that the feldspars themselves represent the variations within whose limits all of the feldspar in the great mass of the rock may be found. A comparison of this plagioclase with that of the very coarse diabase from the boss-like dike forming Pigeon

* All iron determined as Fe_2O_3.

Point, show it to be a little more acid than the latter, though not enough so as to cause it to be placed in a position in the plagioclase scale far removed from that of the feldspar of the diabase [1]. The corresponding figures for the two plagioclases are:

	SiO_2	Al_2O_3	Fe_2O_3 FeO	CaO	Na_2O
Gabbro	51.89	29.68	.69	12.62	3.87
Diabase	53.75	30.39	1.26	10.84	3.76

The augite is generally older than the plagioclase, although the latter mineral seems sometimes to mould the contours of the former one. The pyroxene occurs either in the interstices between the labradorite grains, or as narrow rims around the olivine, forming a mantle that surrounds these and separates them from the feldspar (see Fig. 1).[2] The mineral is very light colored, sometimes being almost colorless, but it is usually tinged

FIG. 1. Section of the olivine-gabbro, exhibiting the tendency of the pyroxene to include olivine grains. Section 1103. × 20.

with pink. It is moreover possessed of a diallagic parting, accentuated by dark decomposition products, the most abundant of which are tiny, irregular black and brown dots. These are scattered everywhere throughout the pyroxene, but are accumulated most thickly in the neighborhood of the cleavage lines. In some of the pyroxene pieces are the peculiar platy inclusions

[1] Bull. U. S. Geol. Survey, No. 109.

[2] Cf. M. E. WADSWORTH, Bull. No. 2, Geol. and Nat. Hist. Survey of Minn., Pl. III. Fig. 1. In this figure the author pictures a pyroxene and olivine bearing the same relation to each other as the diallage and olivine shown in Fig. 1 of this paper.

characteristic of gabbro diallage. These are often arranged in straight lines crossing the parting planes. They are frequently so crowded that the line of inclusions appears as a dark bar crossing the diallage at various inclinations to the cleavage, as in the most notable case (No. 8786), where the direction of the bar cuts the prismatic cleavage at 21° and on the same side of it as the extinction, which is 37° (see Fig. 2). Under polarized light the diallage appears as though polysynthetically twinned. The lamellæ holding the inclusions polarize with a slightly different

FIG. 2. Inclusions in Augite. Section 8786. × ca. 18.

color from that of the inclusion-free lamellæ. Moreover, the material in the immediate vicinity of the several inclusions seems to be more changed from its original condition than portions of the same lamellæ at a greater distance from them. This would indicate that the inclusions have absorbed some of the material of the pyroxene in their growth, and consequently that they are not original inclusions, as are those found by Williams[1] in the Cortlandt peridotites and norites, but are secondary like those discovered by Judd[2] in the peridotites and gabbros of the Western Islands of Scotland.

Under high powers a second cleavage can be detected as a series of fine lines perpendicular to the prismatic cleavage, in sections parallel to the vertical axis. Along these cleavage lines are disposed the inclusions with their long axes so arranged in the direction of the lines as to suggest that the latter were planes of easy solution—that the decomposition of the diallage first took place along them, and then attacked the pyroxene on both sides.

[1] Am. Jour. Sci., 3rd ser., vol. 31, 1886, p. 33; and vol. 33, 1887, p. 141.

[2] Quart. Jour. Geol. Soc., London, vol. 41, 1885, p. 354.

The only other alteration noticed in the diallage is along its edges, where brown and green hornblendes are developed, and in one case where the pyroxene is replaced in part by rosettes of chlorite that polarize in bright blue tints. The very deep pink color of some of the diallage plates may be due to incipient alteration, as along with the change in color there is produced a finely fibrous structure. The writer has searched earnestly for indications of enstatite[1] in the rock under consideration, but has failed to discover any, though strongly pleochroic hypersthene is present in large quantity in certain of its phases to be mentioned later. In one or two specimens of the normal gabbro there is also a little hypersthene, but it is not finely fibrous, and it occurs as very compact plates side by side with equally compact and very fresh plates of diallage.

Much of the pyroxene, as has been said, is in the interstices between the plagioclase and therefore is probably younger than this constituent. It is, however, not in the ophitic areas characteristic of diabasic pyroxene, but is usually in narrow stringers between the feldspar grains, and between these and the olivine. In some sections every grain of olivine is thus separated from plagioclase (Fig. 1), while in other sections, where this is not the case, the diallage is in too small quantity to serve this purpose. Narrow rims of this mineral also exist around magnetite and biotite, and they occur between these two minerals and olivine and a fibrous growth that surrounds them, especially the olivine, in a manner resembling a reaction rim.

Attempts to isolate the diallage for analysis were not successful, as it was found impracticable to free its powder from hypersthene and the brown earthy decomposition products of olivine.

The last mentioned mineral is usually quite fresh, and in large quantity, though in a few specimens it is represented by only an occasional grain in the thin section. Since it was one of the first separations from the magma yielding the rock, it is always present in more or less well defined idiomorphic grains. These are

[1] Cf. M. E. WADSWORTH: Nos. 787 and 692, pp. 90 and 91. Bull. No. 2 Minn. Geol. Survey.

transparent and almost colorless. In thick pieces a yellowish green tinge may be noticed, but in thin slices no recognizable tint may be detected. The inclusions are opaque dendritic particles, spongy magnetite, and secondary products, among which may be mentioned yellowish serpentine, chlorite, and opaque and yellowish-brown earthy substances. These may occasionally entirely replace the original mineral, but more frequently they occur only in the cleavage and other cracks in the fresh olivine, or along its edges.

In most cases the olivine is so fresh that it was thought worth while to have an analysis of it. This has been made by Mr. Hillebrand, who had furnished him a powder consisting of beautifully fresh olivine intermingled with a little diallage, the mixture having been separated from rock No. 8589 by means of methylene iodide. The olivine was isolated by digestion with hydrochloric acid, and the solution obtained was analyzed with this result:

SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	CoO	NiO	CaO	MgO	H_2O	Total.
35.58	1.22	.92	tr.	33.91	.35	.20	?	.90	26.86	.31	100.25

The olivine is thus a hyalosiderite with Mg : Fe about 1½ : 1. The small quantities of manganese and cobalt present in it are of interest from the point of view of Sandberger,[1] as affording another indication that olivine is frequently that constituent of a rock which is the source of the material for ore segregations. In the present instance they are of little significance, however, since so far as known the only ores occurring within the large areas covered by the basal gabbro are magnetite and ilmenite. At Copper Lake, in Secs. 9 and 10, T. 64 N., R. 4 W., weathered masses of the gabbro are stained with a green coating of malachite, and the same[2] staining has been noticed at the contact of the Pigeon Point gabbro with a red granophyric rock, where it has resulted from the alteration of chalcopyrite, but in neither case is the copper compound in sufficient quantity to constitute an ore.

[1] Cf. J. F. Kemp: A Brief Review of the Literature of Ore Deposits. School of Mines Quarterly, XI., No. 4, p. 366.

[2] Bull. U. S. Geol. Survey, No. 109.

The relation existing between the olivine and the diallage is the most interesting of the phenomena presented by the rock. It has already been stated that but very few olivine-grains are in direct contact with feldspar. Around nearly all are narrow rims of pyroxene. At first glance these appear to be a sort of reaction rim between the two minerals, but a more careful study of the sections disposes of this assumption, for the surrounding rim frequently broadens out and merges into a well defined diallage plate (Fig. 3). In consequence of the occurrence of the olivine and augite in the manner described sections of the rock exhibit a

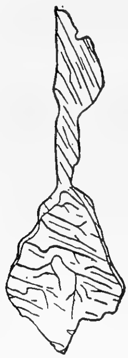


FIG. 3. Olivine partly surrounded by narrow rim of pyroxene, which is continuous with large plate of same mineral. 8803. × ca. 18.

kind of concentric structure, with the rounded olivine grains surrounded by a zone of diallage, and imbedded in a mass of plagioclase. Perhaps the most perfect exhibition of this association of the three minerals is shown in the section of rock No. 1103 from the Cloquet River, where the augite is in such large quantity as to completely envelop the olivine (see Fig. 1).

When the pyroxene is in smaller quantity the rim is much narrower, and in many cases is in its turn separated from the plagioclase by a fibrous growth between the last named mineral and itself. This fibrous growth imitates in great perfection many of the reaction rims described by various investigators[1] as exist-

[1] TORNEBOHM: Neues Jahrb. f. Min., etc. 1877, pp. 267 and 384. A. A. JULIEN: Geology of Wisconsin, vol. 3, p.235, Pl. 22. F. BECKE: Min. u. Petrog. Mitth. 1882,

ing between olivine and plagioclase in many basic rocks. It usually consists of very fine fibres extending perpendicularly from the bounding surfaces of the diallage rim, or when this is lacking, from the peripheries of the olivine grains. In a few instances the fibres form radial groups, centering at points on the exterior of the surrounded mineral. The growth is especially noticeable in the vicinity of the olivine, but it is occasionally also found bordering magnetite grains (Fig. 4) and flakes of biotite. The fact that the fibres are not confined to the borders

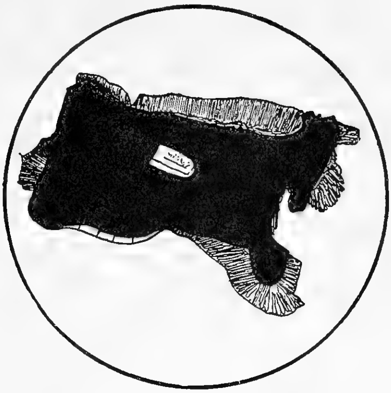


FIG. 4. Fibrous intergrowth around magnetite (?) Between the latter mineral and the fibrous rim can be seen a narrow zone of diallage. Section 10439. × 20.

of olivine, but are found as well around magnetite, biotite,[2] and outside of the diallage rims around olivine grains, is presumptive evidence that the growth is not of reactionary origin.

Between crossed nicols portions of the fibrous zone polarize brilliantly, while other portions have the pale blue tint of thin feldspar. Under very high powers the individual fibres are discovered to be discontinuous. They branch, fork and bend in a fantastic manner, and sometimes stop abruptly, while new fibres begin their courses some distance beyond and continue to the edge

iv., pp. 330, 350, 450. G. H. WILLIAMS: Bull. U. S. Geol. Survey, No. 28, p. 52. M. SCHUSTER: Neues Jahrb. f. Min. etc., B. B. v. p. 451. TEALL: Mineralogical Magazine, Oct. 1888, p. 116. LACROIX: Bull. Soc. France d. Min., 1889, xii., p. 83.

[2] The biotite is probably secondary so that the occurrence of the fibrous rim around it is of little importance as an aid in determining its nature.

of the rim. It is impossible to determine the character of the fibres in the finest rims, but in those in which the structure is coarser, it is learned that two components are present. One is possessed of a high index of refraction, and strong double refraction, and this appears to be continuous with the diallage of the narrow zones interposed between the fibrous growth and the surrounded olivine. The other component penetrates between the pyroxene fibres, and has club-shaped ends. Occasionally the twinning bars of plagioclase may be detected in it, and hence it is assumed to be a triclinic feldspar. The fibrous rim is thus an intergrowth of plagioclase and augite, both of which minerals are normal constituents of the gabbro. In the fibrous rims they have evidently crystallized contemporaneously, whereas in the main body of the rock the main portion of the diallage preceded the plagioclase in its separation from the magma. There is no necessity for regarding the intergrowths as in any way connected with reactionary processes, while there is abundant reason for believing them to be due solely to the tendency of simultaneously crystallizing minerals to mutually interpenetrate each other. This tendency is well recognized as existing to a marked degree between quartz and orthoclase, whereby granophyre is formed, and to a less extent between various other minerals. Micropegmatitic intergrowths between hornblende and feldspar, for instance, have been described by Lévy,[1] Camerlander[2] and Lacroix,[3] between hornblende and quartz by Kalkowsky,[4] between garnet and feldspar by Becke,[5] and between garnet and quartz by Lacroix (l. c., p. 317,) between diopside and quartz by Lévy,[6] and between various monoclinic pyroxenes and plagioclase by Becke (l. c.), Camerlander (l. c.), Lacroix (l. c., pp. 316 and 318), and Lévy.[7] In the Minnesota rock the diallage in many

[1] Bull. Soc. Min. d. Fr., 1878, p. 41.

[2] Ref. Neues Jahrb. f. Min., etc., 1888, II., p. 52.

[3] Bull. Soc. Franc. d. Min., 1889, XII., p. 319.

[4] Gneissformation, des Enlengebirges, p. 41.

[5] Min. u. Petrog. Mitth. 1878, p. 406.

[6] Bull. des Serv. d. l. Carte geol. d. l. France, No. 9, 1890, p. 7.

[7] Ib. p. 7.

instances sends out tongue-like processes that penetrate far into the plagioclase in which the pyroxene is imbedded (see Fig. 5), so that there can be no doubt that the conditions were favorable to the formation of intergrowths between these two minerals during the period when they were separating from the rock magma. The only essential differences between the fibrous

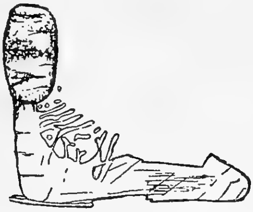


FIG. 5. Diallage plate and olivine grain in plagioclase. The augite in the bend extends out into the feldspar, giving rise to an intergrowth, very like that of the fibrous rim. 8803. × ca. 20.

intergrowths and that illustrated in this figure are, first, the finer structure of the former, and second, its occurrence around the older components of the rock. Neither of these differences is important, however. Only the second needs a moment's consideration.

The position of the fibrous growth around the olivine and other minerals is due not necessarily to the fondness of the intergrowth for this place, but simply to the fact that the diallage, during the earlier stages of its growth, fastened itself to the solid particles in its vicinity and coated them with an envelope of its material. Continuing its growth it formed the encircling rims of this material that are so characteristic of many specimens of the gabbro, and, when the feldspar began to separate it formed with this the granophyric intergrowth. Since the position of the diallage had already become fixed, the intergrowth naturally was compelled to occupy a place just without this and around the minerals which the diallage had already partially or entirely encircled.[1] Though a fibrous intergrowth of pyroxene and plagioclase with the aspect of a reaction rim surrounding the older minerals of a rock is a rare phenomenon, it is not a unique one, for

[1] For fuller description of the intergrowth, see author's paper in Am. Jour. Sci. XLIII., 1892, p. 515.

Camerlander,[1] in 1887, described a similar intergrowth of these two minerals around the garnets of a contact rock from Prachatitz, in the Bohemian Forest, and mentioned that it strongly resembled the kelyphite rims around garnets in serpentine.[2]

Biotite is present in many sections of the gabbro, though not in all. It not only occurs in the neighborhood of magnetite, where this mineral is in contact with plagioclase, but it is sometimes found imbedded in the feldspar and augite, and at other times it forms a mosaic with decomposed diallage. In basal sections it is reddish brown, and in longitudinal sections is light yellow normal to the cleavage, and dark brownish-green, almost opaque, parallel to this structural feature. In all cases it is probably secondary, for, even when it apparently occurs alone, a very close inspection of its sections will often reveal remnants of magnetite grains imbedded in it. This form of the mineral is evidently a reaction product between the magnetite and the plagioclase by which it is surrounded. The remainder of the mica is probably derived mainly from diallage, since when this mineral is perfectly fresh biotite is absent from the rock, and when the pyroxene has undergone any kind of decomposition, little flakes of biotite are intimately intermingled with its undoubted alteration products. In the broad pieces of diallage in which the dark platy inclusions are so common, little flakes and tiny needles of biotite are frequently discovered lining the cleavage cracks, so that such pieces not uncommonly are crossed by two sets of inclusions cutting each other at some acute angle, one set comprising the gabbroitic kinds already described, and the other set the biotite plates along the cleavage cracks.

Magnetite is widespread throughout the rock, but it is not abundant in most sections. It is in small grains, and in tolerably large areas that are broadly rod-shaped or very irregular in outline. In most cases it occurs between neighboring plagioclase

[1] Jahrb. d. K. K. geol. Reichsanst, 37, 1887, p. 117.

[2] The writer is informed by Dr. J. J. Sederholm that intergrowths similar to those occurring in this Minnesota rock are common in Norwegian gabbros and in one from Ylivilska, in Finland. In his university lectures Professor Brögger calls them "coronites."

grains, but sometimes it is included within them. The larger part of the mineral is undoubtedly primary, while a smaller portion is probably secondary. By its alteration it gives rise to biotite, as mentioned above, through reactions set up between it and the contiguous plagioclase, so that often a grain of the magnetite is entirely surrounded by a true reaction rim composed entirely of biotite. Leucoxene decomposition products were not once observed.

Nowhere in the normal gabbro does the magnetite occur in sufficient amount to constitute an ore, but in certain phases of the rock that have lost entirely the gabbro characteristics, it is known to exist in great quantities. Prof. Winchell[1] describes these ores in detail and gives analyses of them; but most of the titaniferous magnetites of this author's gabbro-titanic-iron group do not occur in the normal rock of his basal mass. They are found either in its peculiar phases to be described later, or in the Animikie and Keweenawan coarse-grained diabases, whose magnetite is always highly titaniferous, and in which there is always an abundance of leucoxene. Only a few qualitative tests have been made on the magnetite separated from the gabbro, but they all agree in showing no trace of titanium. If, upon further investigation, it is found that an absence of titanium from the magnetite of the basal gabbro is characteristic for the rock, an important difference will have been discovered as existing between it and the rocks of the interleaved flows of nearly similar composition in the underlying and overlying series.

The only other original component seen in any sections is apatite. This is in the usual form, as colorless, acicular crystals imbedded in feldspar, and in the various alteration products of the diallage and olivine. It is present only in very small quantity.

Quartz is rare as a secondary substance, mingled with other secondary products in the most altered phases of the rock. In one section (No. 8796) it is filled with tiny, opaque, acicular inclusions.

In order to learn something of the limits through which the rock varies in its chemical composition two specimens were

[1] Bull. No. 6. Minn. Geol. Survey, p. 117 and 125.

analyzed by Dr. H. N. Stokes of the laboratory of the U. S. Geological Survey. No. 8589 contains a large proportion of diallage and olivine, while No. 8786 is more nearly of the average composition of the entire mass.

	8589	8786
SiO_2	45.66	46.45
TiO_2	.92	1.19
P_2O_5	.05	.02
Al_2O_3	16.44	21.30
Cr_2O_3	tr.	
FeO	13.90	9.57
Fe_2O_3	.66	.81
NiO	.16	.04
MnO	tr.	tr.
CaO	7.23	9.83
MgO	11.57	7.90
K_2O	.41	.34
Na_2O	2.13	2.14
H_2O at 105°	.07	.14
H_2O above 105°	.83	1.02
Total,	100.03	100.75

The larger percentages of Al_2O_3 and of CaO in 8786 as compared with 8589, and the smaller percentages of FeO and MgO, substantiate the results of the microscopical study. An increase in the proportions of Al_2O_3 and CaO indicates an increase in labradorite, and a decrease in FeO and MgO, a decrease in the iron-bearing minerals olivine and diallage. The variations are somewhat larger than was to be expected in a rock so uniform in structure and so monotonous in composition as that of this great mass, but they are easily accounted for by the local accumulation of certain of its heavier constituents. So far as known there are no "schlieren" in the normal rock nor any other evidences of a differentiation ("spaltung") of its magma before cooling, so that the variations in mineralogical and chemical composition must be looked upon as due purely to accidental causes. Moreover, the differences are not great enough to effect any material impression upon the rock as a whole. Its characteristics are practically identical throughout an area of several thousands of square miles, and are

quite different from those of the comparatively thin flows between the sedimentary layers of the Keweenawan.

Prof. Winchell, in his bulletin on The Iron Ores of Minnesota, asserts[1] that the "gabbro is found associated with red syenite, quartz-porphyry and various sedimentary rocks in northeastern Minnesota, and, indeed, it passes through unimportant petrographic changes into the well known 'traps' of the cupriferous formation, from which it has not yet been possible to separate it by any important lithologic or stratigraphic distinctions." But since Prof. Winchell has included within his gabbro the rocks of Bellissima Lake, Carlton's Peak and the feldspar masses enclosed in the dark trap of Beaver Bay, it is plain that he does not confine his remark to the rock to which the writer is now limiting his attention, viz., the great coarse gabbro which Irving described as the great basal flow of the Keweenawan. This rock, as has been shown, by a study of specimens taken from very many different localities (see list of specimens studied, p. 714) within the area underlain by it, is so very uniform in its characteristic features that no difficulty is experienced in distinguishing its thin sections from those of any other rock in Minnesota north of Lake Superior.

Summary.—The microscopical study of the gabbro of Irving's "basal flow" at the bottom of the Keweenawan in Minnesota reveals a rock which is uniform in texture and composition throughout its entire extent. It is composed of magnetite, olivine, diallage and labradorite as essential constituents, with a little biotite and occasionally a very small quantity of quartz as secondary components. Its structure, or better texture, is typically granitic in that all of its comprising minerals are hypidiomorphically developed, with the plagioclase younger than the diallage. In this respect the rock is essentially different from the so-called gabbros of the thick flows interbedded with the clastic beds of the Animikie series and the Keweenawan group in the same region, for in the latter, notwithstanding the

[1] L. c., p. 124.

coarseness of their grain, the plagioclase is always older than the diallage, and it always possesses in greater or less perfection the lath-shaped sections characteristic of diabasic feldspar. This being the case, it seems possible that the great gabbro of north-eastern Minnesota is not a "flow" or a "series of flows," but is the solidified reservoir [1] in which later flows originated or is a batholitic mass, as Winchell[2] has latterly come to call it.

Further field work on the geological relationships of the mass will probably show either that it is a batholite within the Keweenawan series, well down toward its base, or that, like the anorthosites of Lawson it is an eroded "massive" upon the top of which the later Keweenawan beds have been deposited.

LIST OF SPECIMENS OF NORMAL GABBROS STUDIED AND THEIR LOCATIONS.

1103 (338) 400 N. 200 W. S.E. corner Sec. 34, T. 53 N., R. 13 W., Minn.
6007 (1415) S. side Cross Lake, S. side Sec. 29–64–1 W.
(1416)
(1424)
6011 (1126) S.E¼ Sec. 21–64–3 W.
6013 (1127) N.W. side Copper Lake, Sec. 9–64–4 W.
6127 (1171) N.E¼ S.W¼ Sec. 36–65–3 W.
6128 (1172) S.E¼ S.W¼ Sec. 36–65–3 W.
6130 (3203) S.E¼ S.E¼ Sec. 36–65–3 W.
7025 (2091) S. shore Akeley Lake, Sec. 29–65–4 W.
8589 (4025) S. shore of small lake in S.E¼ S.E¼ Sec. 19–63–9 W.
8786 (3520) Near S.¼post of Sec. 35–61–12 W.
8788 (3528) N. shore Birch Lake, 200 paces E. of S.¼post Sec. 24–61–12 W.
8789 (3529) W. side Birch Lake, opposite N.E. arm of lake, Sec. 24–61–12 W.
8792 (3532) N.W¼ S.W¼ Sec. 9–62–10 W.
8793 (4259) N.W¼ S.E¼ Sec. 23–62–10 W.
8794 (3522) On Mishiwishiwi river, near centre Sec. 34–62–9 W.

[1] Cf. *ante*, p. 696.

[2] Bull. No. 8, Geol. and Nat. Hist., Sur. of Minn. Preparatory note, P. xxiv. *et seq.*

8795 (3534) On Mishiwishiwi river, near centre of N½ T. 61–7 W.
8796 (3848) On Mishiwishiwi river, about 2 miles E. of 8795.
8800 (3535) On Mishiwishiwi river, near S. side T. 62–8 W.
8803 (3537) S.E¼ N.E¼ Sec. 7–63–8 W., 250 paces S. of S.E. point of Snowbank Lake.
8869 (4061) S.E¼ Sec. 14–64–7 W.
8896 (3856) N.W¼ Sec. 6–64–5 W.
10000 (3691)
10438 (5068) Half way down W. side Greenwood Lake, Sec. 29–64–2 E.
10439 (5069) Outlet Greenwood Lake, Sec. 33–64–2 E.
10440 (5013) Ca. S.E¼ Sec. 8–59–10 W.
10441 (5014)
10442 (5015)
10443 (5016)
10444 (5070)
10445 (5071)
In order from S. to N. along a stream running from a small lake northward into Birch Lake. First specimen from about N. side of T. 59 R. 10 W.
10537 (5160) S.E¼ S.W¼ Sec. 33–65–5 W.
10538 (4985) S.E¼ S.E¼ Sec. 32–65–5 W.
10539 (4986) S.W¼ S.E¼ Sec. 32–65–5 W. East end of portage between lake Kabamitchikamak and small lake in Sec. 32–65–5 W.
10569 (5181) 1200 paces south N.W. corner Sec. 29–65–4 W.
10570 (4995) 1500 paces S. of N.W. corner Sec. 29–65–4 W.
10638 (5242) North of centre of Sec. 18–64–3 E.

SHOWING APPARENT REACTION RIMS.

6130 (3203), 7025 (2091), 8792 (3532), 8793 (4259), 8795 (3534), 8800 (3535), 8803 (3537), 10000 (3691), 10439 (5069), 10442 (5015), 10444 (5070).

NOTE.—The first number given in each case is the number of the specimen in the collection of the Lake Superior Division of the U. S. Geol. Survey. The numbers in parentheses are those of the corresponding thin sections.

W. S. BAYLEY.

WATERVILLE, ME., July 1, 1893.

Correction.— In the reference (on page 591 of this Journal) to Dr. Wadsworth's work on the Intrusive Basic Rocks of the Marquette region, the date of the publication of the "Notes on the Geology of the Iron and Copper Districts of Lake Superior," is given as 1881. It should be 1880.

It is also stated on the same page that Wadsworth declared these rocks to consist largely of diabase and coarse basalt, both massive and slightly schistose. It was, of

course, not intended by the use of the word "slightly" to intimate that the author did not recognize the true nature of the green-schists of the region. It is well known that in the article referred to that he emphasized particularly the fact that the schists are metamorphosed basic eruptives. He also showed that many of the rocks which still preserve their diabasic and basaltic characters are nevertheless "slightly" schistose, and it is this fact to which it was desired by the writer to call especial attention. This correction is made to prevent misapprehension of the writer's attitude toward the valuable contributions of Dr. Wadsworth to our knowledge of the greenstone-schists of the Lake Superior region. Vide also: Report of the State Board of Geological Surveys for the years 1891 and 1892. Lansing, 1893. Pp. 124–125 and 133–141.

W. S. B.

ON THE GEOLOGICAL STRUCTURE OF THE MOUNT WASHINGTON MASS OF THE TACONIC RANGE.

(With Two Plates.)

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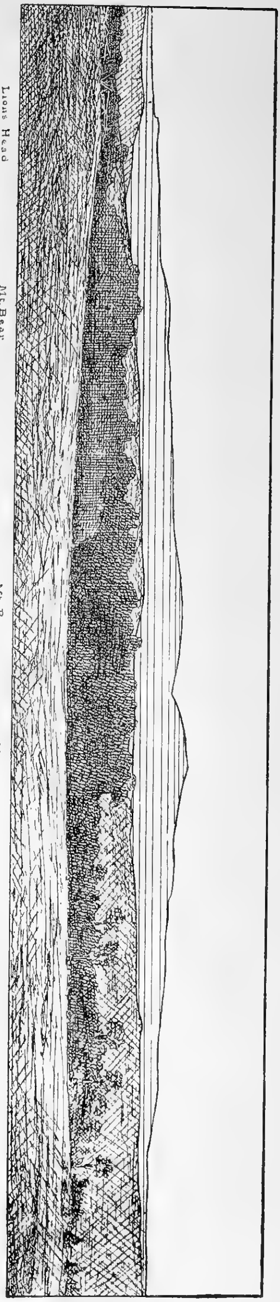
CONTENTS.

THAT portion of the Taconic Range which is known as Mount Washington is both topographically and geologically a unit. It covers an elongated elliptical area, about fifteen miles in length and four and one-half miles in average breadth, lying in the states of Massachusetts, Connecticut and New York. It occupies the entire township of Mt. Washington, and portions of Sheffield and Egremont in Massachusetts; about one-third of Salisbury in Connecticut; and portions of Northeast, Ancram, Copake and Hillsdale in New York.

Topography.—The Mt. Washington mass is a double ridge enclosing a summit plain. Mt. Everett, or the "Dome of the

Taconics" (2624 feet) lying in the eastern ridge, is the highest peak and one of the highest elevations in Massachusetts, while Bear Mountain (2355 feet) is the highest point of land in the state of Connecticut. The main summit plain is situated to the northward of the center of the mass and has an average altitude of about 1700 feet. Corresponding with the elliptical outline of the mountain, this plain is compressed at the north and south, so that its length is about three miles and its breadth two miles. Encircling it is a line of peaks ranging from 1900 to 2600 feet in height. This encircling wall of peaks is buttressed by other peaks both to the northward and southward, the southern side being strengthened by a parallel belt across the mountain, composed of Mts. Bear, Gridley, Frissell and Monument. Southward of this belt of hills the elevated plateau recurs, but without the rampart of peaks which characterize it in the northern and more central area.



MOUNT WASHINGTON, MASS.
FROM THE EAST
FIG. 1

The Salisbury-Sheffield valley on the east and the Copake Hillsdale valley on the west of the mass, constitute a floor having an average altitude of 700 feet, from which Mt. Washington rises abruptly, the mean slope-angle being about 20°. The southern boundary of the mountain is the nearly east and west valley

through which runs the Central New England and Western Railroad. On the northwest Mt. Washington is merged into the narrow ridge of the Taconics, which extends northward into Vermont. The name Mt. Washington, however, applies properly to all of the range lying south of the South Egremont-Hillsdale turnpike. The regular elliptical contour of the mass is broken on the northeast by two deep embayments, the eastern one containing Fenton Brook, and the western, which is knee-shaped, being occupied by Sky Farm Brook. The regularity of contour is further interrupted by an outjutting spur on the west side, known as Cook's Hill. South of the topographical break which limits the mountain in the neighborhood of Ore Hill, the range of the Taconics pursues a more interrupted course, the hills becoming smaller and spreading out considerably.

Previous Work within the Area.—As the aim of this paper is mainly to deal with the problem of mountain structure, no mention will be made of the part which the area has played in the "Taconic Controversy," except as structural facts may be brought out by it. The boundary between the basement limestone and the schistose rock of the mountain was roughly located by Hitchcock[1] for the northern portion, and by Percival[2] for all but the extreme northern portion of the mountain. The former gives (Plate 55 E of the work cited) a section across Mt. Washington, in which the schist and limestone of the east base of Mt. Everett are shown dipping at a steep angle east. Mather[3] gives two sections across the Taconic Range in the vicinity of Mt. Washington. One of these (loc. cit. Pl. XIV, Fig. 1) is from Hillsdale, N. Y. to Egremont, Mass., and passes a little to the north of Mt. Washington; the other (Pl. XVI, Fig. 3) is from Hudson, N. Y., to the southwest corner of Canaan, Ct. The latter crosses the mountain in a northwest-southeast direction and exhibits a synclinal structure.[4]

[1] Geol. of Mass., EDWARD HITCHCOCK, Amherst and Northampton, 1841, Frontispiece Map.

[2] Rept. on the Geol. of the State of Connecticut, J. H. PERCIVAL, New Haven, 1842, Frontispiece Map.

[3] Natural History of New York, pt. iv. Geology, pt. i. 1845.

[4] In his list of dip and strike observations MATHER includes several from the Mt. Washington area (pp. 612–613).

In 1864 James Hall and Sir William Logan [1] visited Mt. Washington and described it as probably synclinal in structure.

The only investigator, however, who has made a detailed study of the geological structure of the mountain is Professor J. D. Dana, whose papers on the subject have appeared mainly in the American Journal of Science. His first paper dealing with the structure of Mt. Washington [2] appeared in October, 1873. It contains a sketch-map with dip and strike observations. On page 38 he states:

"*Mt. Washington is a synclinal with limestone below and slate above.*"

And on page 39:

"We thus find evidence of a very broad synclinal across the center of Mt. Washington. But just north, in Egremont, the structure is totally different; the ridges S and T [3] are the sources of very steep and comparatively narrow independent synclinals with the axial plane inclined westward. * * * The synclinals S and T become merged in one mass in Mt. Washington; and as the limestone does not appear at the smmmit, the intermediate anticlinal in the mountain was only an anticlinal of slate. In other words, the synclinal of limestone beneath the mass of the mountain was one great trough with breaks and incipient flexures; while to the north these incipient flexures became two defined synclinals, with the intermediate anticlinal—the synclinals being courses in the ridges S and T and the anticlinal that of the limestone outcropping between; and then, farther north, there was formed the Taconic synclinal T alone."

In the same year there appeared in the Proceedings of the American Association a paper entitled "The Slates of the Taconic Mountains of the age of the Hudson River or Cincinnati Group.[4] In this paper Professor Dana states that limestone dips west under slates along the east slope of Mt. Washington for four miles, "that is, the whole eastern front." He describes

[1] Paper read by T. STERRY HUNT before the Natural History Society of Montreal, October 24, 1864. Reviewed in the American Journal of Science, 2d ser., Vol. xl, p. 96 (1865).

[2] On the Quartzite, Limestone and Associated Rocks of the vicinity of Great Barrington, Berkshire county, Mass., J. D. DANA, American Journal of Science, 3d ser., vol. vi., p. 37.

[3] The ridge S is that of Mts. Darby, Sterling and Whitbeck, and the ridge T that of Mts. Prospect and Fray near the New York-Massachusetts state line. (Cf. map pl. i).

[4] J. D. Dana, Proc. A. A. A. S., 22d (Portland) meeting, 1873, pp. 27–29.

the mountain as composed of two close-pressed synclinals in the Mt. Washington plateau with steep easterly inclined axes, and that these synclinals are synclinals of slate riding over a single synclinal of limestone.

In 1877, in a paper entitled, "On the Relations of the Geology of Vermont to that of Berkshire,"[1] he adds, referring to the anticlinals of limestone between the three northern spurs of the mountain:

"It has not been possible to follow these subordinate anticlinals southward, because the limestone is not continued far in that direction, and the summit of the mountain is under soil and cultivated farms. But yet the fact of flexure at the north end is strong reason for believing that similar flexures, if not the same continued, characterize the whole length from north to south of the mountain-mass, such a slate easily flexing under uplifting lateral pressure. This is further sustained by observations proving that other subordinate anticlinals exist on the western slope of the mountain, in the vicinity of Copake Furnace. Close to the western foot there are two nearly parallel limestone areas, parallel to the axis of the range. The inner (or more eastern) one is about a mile long, and the other about half a mile. They are separated from one another by a thin belt of hydromica slate, and the same slate exists on the other sides. The dip of the beds of limestone and slate is to the eastward 50°, the strike averaging N. 15° E. (true). They are evidently registers of local folds—anticlinal and synclinal, the former bringing up the limestone."

In the paper "On the Hudson River Age of the Taconic Schists,"[2] Professor Dana has put on record new observations showing the synclinal character of the mountain (l. c., p. 376) and printed a map including a part of Mt. Washington (p. 379)[3].

Another paper, "On the Southward Ending of a Great Synclinal in the Taconic Range,"[4] is specially devoted to a consideration of the structure of Mt. Washington, and contains a map of the southern portion of the mountain on a scale of eight-tenths of an inch to the mile. Professor Dana's earlier conclusions as to the synclinal character of the mountain, had been largely drawn from observations made in Massachusetts. The conclusion that the synclinal character of the northern portion of the mountain is continued to the southern extremity, he drew from the fact

[1] Am. Jour. Sci., 3rd ser., vol. xiv., pp. 262–263.

[2] Am. Jour. Sci., 3d ser., vol. xvii., pp. 375–378 (May, 1879).

([3] Cf. also *ibidem*, Supplement to vol. 18, for dip and strike observations).

[4] *Ibidem*, vol. xxviii., p. 268 (Oct., 1884).

that a number of small limestone areas near Lakeville, in which the strata are but gently inclined, are capped by a schist. This schist he believed to be the same as the schist of the southern extremity of the mountain. He says, speaking of these areas (p. 272):

"Since the limestone is the underlying rock, they are all, if not monoclinal, as is hardly possible, small overturned anticlinals, which have had their tops worn off so as to show the limestone beneath." * * * * * *

"The synclinal structure of the mountain is apparent also along portions of the southern edge of the schist. At Ore Hill, one and a half miles west of Lakeville, the schist overlies limestone."

On page 273 he says:

"The ore-pits that have been opened about the base of Mt. Washington, fourteen in number, are situated near the junction of the limestone and schist, and in view of the facts that have been mentioned, this means—*near where the limestone emerges from beneath the schist.*"

Referring to the dying out of the synclinal to the south of the mountain, he says:

"Again the pitch of the beds in the last three miles is southward in some parts, instead of eastward or westward, showing a flattening out of portions of the synclinal and subordinate anticlinals."

"It thus appears that in the dying out of the synclinal, besides a flattening of portions of the general synclinal and the introduction of southward dips, there was also a multiplication of small subordinate flexures."

"Farther there is a multiplication of ridges of schist in the limestone area."

"Several such ridges, some quite small, are situated, as the map shows, southeastward of the mountain near the village of Salisbury; and others occur farther east. They consist of the same mica schist as the mountain,—they have generally an easterly dip, often a high dip; and the facts seem to show that most of them are *synclinal* flexures; that they occupy the troughs of local synclinals in the limestone; * * * . Most of them were, apparently, half-overturned troughs so pushed over westward that the dip of the schist is generally eastward." * * * * * * *

The following is quoted from a paper[1] entitled "Berkshire Geology" (pp. 15–16):

"The Mt. Washington schists lie in a trough very much like that of Greylock, but one relatively shorter in its narrowed part and reversed in position. In the northern half the trough is a very broad shallow one, while to the south the east side is pushed up westward."

[1] Berkshire Geology, by Prof. JAMES D. DANA. A paper read before the Berkshire Historical and Scientific Society of Pittsfield, Mass., February 5, 1885. Pittsfield, 1886.

In Professsor Dana's last series of papers[1] on the Taconic Area, he adds some strike and dip observations and prints a more complete map of the area. In the second of the papers,[2] on pages 439–442, he describes the variations in character of the schist of Mt. Washington as showing a more intense degree of metamorphism in the eastern portions, and in conclusion states (p. 441): "The facts here reviewed relate, it should be remembered, to a single stratum, that overlying the limestone."

The several extracts above given will, I think, sufficiently explain Professor Dana's views regarding the structure of Mt. Washington.

On the geological map of the Taconic area compiled by Mr. C. D. Walcott,[3] the Mt. Washington mass is indicated having the same relations to the rocks of the adjoining areas as is shown on Prof. Dana's map.

Conditions and Progress of the Present Investigation.—The writer made a partial reconnaissance of Mt. Washington in the season of 1889, but the mapping was largely done during the months of July and August, 1891. He was assisted during the season of 1891 by Mr. Louis Kahlenberg, at present instructor in chemistry in the University of Wisconsin. Mr. Kahlenberg has traced the contact of schist and limestone along the west base of the mountain. The work has been in charge of Professor Raphael Pumpelly, then chief of the Archean Division of the U. S. Geological Survey.

The reconnaissance of 1889 was made on the southeastern flank of the mass and furnished only equivocal evidence concerning the relations of the "Stockbridge" limestone of the valley to the schist of the adjacent flank of the mountain. One of the first results of the work of 1891 was the discovery of a calca-

[1] On Taconic Rocks and Stratigraphy, with a Geological map of the Taconic Region, J. D. DANA, Am. Jour. Sci., 1885 and 1887.

[2] *Ibidem*, 3d ser., vol. xxix., June, 1885.

[3] The Taconic System of Emmons, and the Use of the Name Taconic in Geological Nomenclature, by CHAS. D. WALCOTT, Am. Jour. Sci., vol. xxxv., pl. iii. (May, 1888).

reous horizon occupying the central Mt. Washington plateau, and the locating of its boundaries (cf. map). Observations were then made a little to the north of Salisbury village which showed conclusively that the schist of that vicinity is *below* the limestone, the structure of the mountain at that latitude being essentially an anticlinal. On examining next the northern extremity of the mountain, observations were quite as conclusive in proving that the schist of Jug End is *above* the valley limestone, and that the section across the range at this latitude is essentially what Professor Dana has described. This knowledge that we have to do with two horizons of schist, the one lower and the other higher than the limestone of the Egremont valley, was soon followed by the discovery of lithological differences between the different beds, which have furnished the key to the structure. Topographical features soon suggested a course across the mountain through which the limestone might pass and separate the upper schist of the northern portion from the lower schist of the southern portion. Through this path the calcareous horizon of the Egremont valley, considerably modified it is true, has been carefully traced. A large number of observations have been gathered from all parts of the mountain mass. Each of the numerous peaks has been ascended and as many data as practicable have been collected. At this time the southern portion of the mountain had not been carefully studied. Later in studying the area lying to the east and southeast of the mass of Mt. Washington, it was found that the limestone of that section is divisible into two beds separated by a schist, which is lithologically identical with the lower of the two horizons of schist in Mt. Washington. The evidence supporting this and the manner in which the areal relations are illusive in the indications which they afford regarding stratigraphy, will be set forth in a later paper. The lower of the two limestone horizons was found to extend westward and disappear under the schist of the south end of Mt. Washington. The schist overlying it, which so resembled the lower of the Mt. Washington schists, was also traced along the northern border of the limestone into the southern portion of Mt. Washington. The areal

relations in the vicinity of the mountain are set forth on Plate III.

Horizons Represented.—The Mt. Washington series thus consists, not of two members as supposed by Dana, but of four, two of which are calcareous. The calcareous beds alternate with the schists, which have been shown to possess marked lithological differences. The sequence of these beds is as follows: (a) a calcareous horizon which I designate the Canaan Dolomite from its typical development at Canaan; (b) the lower schist bed, which I call the *Riga Schist* from Mt. Riga peak where it is perhaps most typically developed; (c) a calcareous horizon, which I designate the Egremont Limestone from its wide extent in the Egremont valley (this limestone is much modified in all localities above the valley floor); and (d) the upper schist horizon, to which I give the name *Everett Schist* since it assumes its maximum thickness within the area at Mt. Everett. It will be noticed that this sequence corresponds with that which Dale has determined for the Greylock mass in northern Berkshire county.[1] Below are given in parallel columns for comparison the series of Mt. Washington and Greylock:

Mt. Washington Series.	*Greylock Series* (*Dale*).
1. Canaan Dolomite.	1. Stockbridge Limestone.
2. Riga Schist.	2. Berkshire Schist.
3. Egremont Limestone.	3. Bellows Pipe Limestone.
4. Everett Schist.	4. Greylock Schist.

These beds are probably Ordovician though the lower portion of the Canaan Dolomite may, like the Stockbridge Limestone, be Cambrian.[2] No fossils have as yet been found in the vicinity and it is hoped that further search may reveal them. Walcott[3] has

[1] The Greylock Synclinorium, by T. NELSON DALE. Amer. Geologist, July, 1891, pp. 1–7. Also given in detail in a forthcoming monograph of the U. S. Geological Survey, by Professor RAPHAEL PUMPELLY.

[2] On the Lower Cambrian Age of the Stockbridge Limestone, by J. ELIOT WOLFF, Bull. Geol. Soc. Am., vol. ii. 1891. See also DALE, *ibid.*, vol. iii, pp. 514–519.

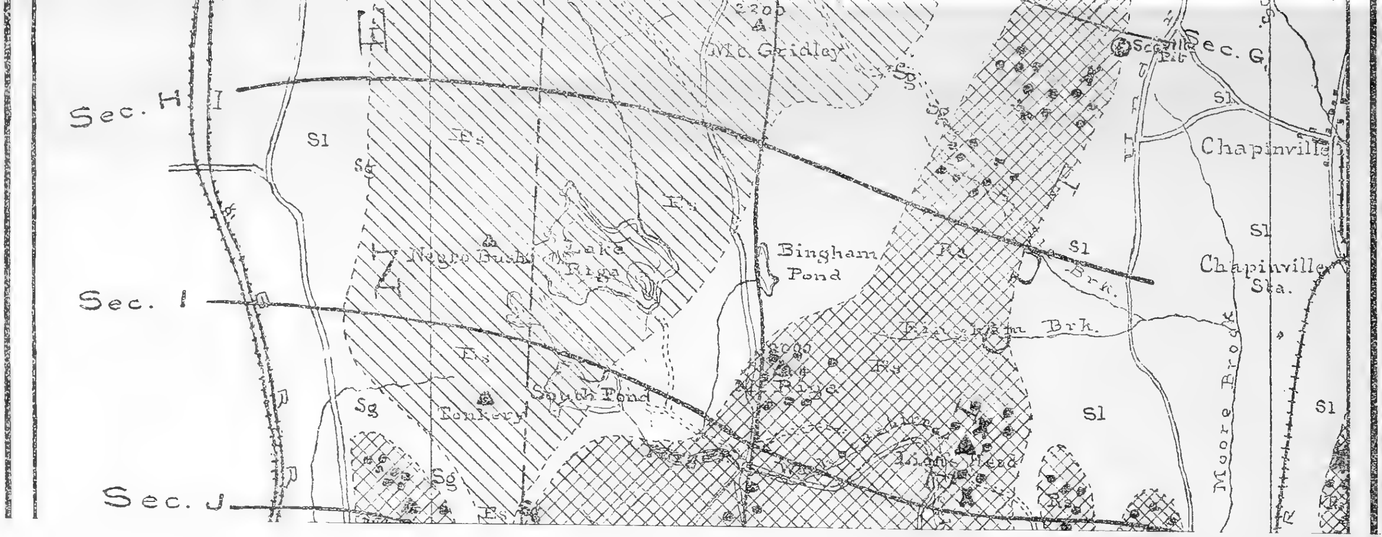
[3] The Taconic System of Emmons, and the use of the Name Taconic in Geological Nomenclature, by CHAS. D. WALCOTT, Am. Jour. Sci., vol. xxxv, pp. 237–242, 399–401, March and May, 1888. (With map).

found Ordovician fossils in the limestone belts some distance to the north and Cambrian fossils at Stissing Mountain to the southwest.

Lithological Character of Horizons.—(a) *Canaan Dolomite.* This bed seems to be very rich in magnesia, the rock being in some cases at least a true dolomite. This is shown by a number of analyses of it by Mr. J. S. Adam.[1] This rock appears at the surface only in the extreme southeastern portion of the area here considered, where it presents few features different from those which are common to the Egremont Limestone. Farther to the eastward, however, and particularly in the vicinity of Canaan, it is often characterized by the presence of interesting metamorphic minerals, the well known salite and tremolite of that locality. Phlogopite also has in one or two instances been found. In its upper layers, where it approaches the overlying Riga Schist, the rock may become graphitic, as at Ore Hill. As it appears in the vicinity of the mountain, however, the rock presents no characters which can be relied upon to distinguish it from the higher Egremont Limestone, and the differentiation is based on stratigraphy alone.

(*b*) *Riga Schist.*—This horizon is tolerably uniform in character, the principal differences being in the presence and variable size of the metamorphic mineral individuals. Strictly speaking the rock is a gneiss, owing to the abundance of feldspar, but in order to distinguish it from more feldspathic and more or less granitoid gneisses lying east of the Housatonic River, it is best to refer to it as a schist, which it most resembles in structure. It almost invariably is porphyritic from the presence of lenticular to spherical grains of an acid plagioclase. The base is usually composed of feldspar, quartz, and a colorless mica (in part sericite) and biotite. Considerable graphite often exists in this base as does also ilmenite. Chlorite when present is usually in small amount. Garnets, staurolite, ottrelite, and biotite, as well as plagioclase, are developed at many localities. On the summit of the Lion's Head the rock contains garnets (rhombic dodeca-

[1] See Am. Jour. Sci., vol. xlv. p. 404, foot note.


Sec. G
Scoville Pit
Chapinville
Chapinville Sta.
Moore Brook
Bingham Pond
Bingham Brk.
Mt. Gridley
Negro Bush
Lake Riga
South Pond
Bonkery
Sec. H
Sec. I
Sec. J
Sl
Sg
Es
R


Preliminary
Geological Map
of
Mt. Washington
Scale of 2 1/100s.
Everett Schist.
Canaan Limestone.
Riga Schist.
Macroscopic Garnets, Staurolite
Mountain Peaks
Ore Pits.
73° 30
73° 25'
Egremont Plain
So. Egremont
Sec. A
Sec. B
Sec. C
Sec. F

hedra) over a centimetre in diameter, and staurolites (usually inclined-cross twins) a centimetre or more in length. Tourmaline occurs only in minute crystals, much less widely distributed than any of the other metamorphic minerals except ottrelite. Some of the localities where macroscopic garnets and staurolites were found in the rock have been indicated on the map—small black circles and crosses standing for the two minerals respectively.

(*c*) *Egremont Limestone.*—This horizon as developed in the valley near the base of the mountain, is a white to gray crystalline limestone, which is often quite pure but for small scales of colorless mica and grains of pyrite. Locally it contains thin quartzitic or schistose layers. Generally it passes upward into the Everett Schist of the flanks of the mountain through a graphitic layer of variable thickness, and a similar graphitic rock is also to be found at its lower contact with the Riga Schist. As met with in the summit plains, the limestone appears under two modifications which grade insensibly into one another. They are (1) a very micaceous limestone or calcareous mica schist; and (2) a graphite schist, often, though not always, calcareous. The first mentioned modification is to be found only in the central portions of the northern summit plain, where the larger streams have cut through the thick drift deposits. It is richest in calcite at two localities, one of which is in the bed of Wright Brook about midway between its confluence with Ashley Hill Brook and the north and south road to the east, and the other is in the bed of City Brook. This rock also occurs in the small brook near the house of H. F. Keith, in the bed of Huckleberry Brook, and at several localities on the Ashley Hill road between Huckleberry and Wright Brooks. It always contains a silvery mica, graphite and pyrite.

In the northern summit plain graphitic schist (here generally calcareous) forms a border separating the micaceous limestone from the Everett Schist which surrounds it. According as it occurs nearer the limestone, it is the more calcareous. In the lower course of Wright Brook it contains layers of calcite over a

centimetre in thickness, while on the road encircling the west flank of Mt. Everett it hardly effervesces at all with acid. At localities south of the central plain the rock only rarely exhibits effervescence with acid. The graphite schist differs from the limestone not only in the large proportion of graphite and the correspondingly small amount of calcite which compose it, but its least calcareous varieties contain also much feldspar and quartz. Garnets and tourmaline have each been found in one specimen, the first near the lower, and the second near the upper schist contact.

(*d*) *Everett Schist.*—The rock of this horizon is not in all cases to be easily distinguished from the Riga Schist. Like that rock it is porphyritic from lenticular feldspar grains, but these feldspars are much more abundant and more constant, and the base is generally more chloritic or sericitic. Ottrelite is found sparingly at some localities. The most striking lithological difference from the Riga Schist, however, exists in the *entire absence of macroscopic garnets and staurolites from this horizon*, not an individual of either species having been found within the entire length and breadth of the area of this horizon exposed, though they have been carefully sought at each locality. The beds seem to become more sericitic along the northwestern foot of the mountain. A phase of the rock which is more characteristic of the southeastern portions of the area is very chloritic with magnetite octahedra sometimes as large a pea. Chloritic phases of the rock also appear in the extreme northern areas.

Explanation of Map, Areal Geology.[1]—The eastern and southern portions of the map are based on the Sheffield and Cornwall sheets of the topographical map of Massachusetts and Connecticut by the U. S Geological Survey, and the portion of the map lying in New York State is compiled from older road maps. The manner in which the Egremont Limestone crosses the mountain separating the Everett and Riga Schist horizons, may well be emphasized by special description. On the eastern side the course of the calcareous horizon as it gains the summit plain is

[1] See Plate III.

suggested by topography. The series of sections in Figure 2 will show this in some measure.

Beginning with Mt. Everett, we find that it presents a uniformly steep eastern slope of Everett Schist, the limestone being in contact near the Undermountain Road. Where the slope of Mt. Race begins a little farther south, an abrupt recession occurs in the face of the range, which extends west to the foot of steep cliffs and south to the road north of Sage's Ravine. Into and

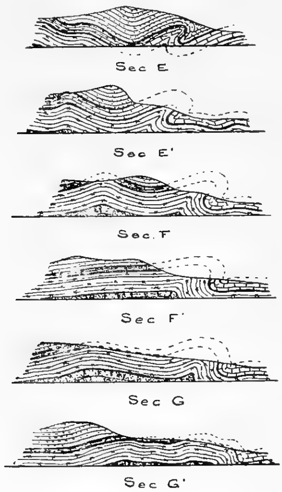


FIG. 2. Series of sections from the east flank of Mt. Washington, showing how the limestone of the valley gains the summit plain.

along this "bench" runs the Egremont Limestone. Proceeding southward from the north end of this "bench," a tongue of schist is met lying within the limestone, about midway between the cliffs and the road, and forming a backbone, the slope immediately west being very gradual while that to the east is tolerably steep. This tongue of schist broadens to the southward, narrowing that belt of limestone which lies to the west of it. As this limestone belt becomes narrowed toward the south, it ascends the mountain, losing as it does so most of its calcite and developing into a black graphitic schist. This reaches the altitude of the summit plain about one-eighth of a mile north of Bear Rock

Falls. From there it is traced with some difficulty along the road to Sage's Ravine, between garnetiferous schists on the east and Everett Schists on the west. The garnets of the eastern schist belt were found to extend northward into the contracted part of the tongue of schist. Immediately north of Sage's Ravine the graphitic rock is distinctly calcareous. West of this point the garnetiferous rock occupies the bed of Sage's Ravine as shown on the map and in sections, while the Everett Schists occur on the road above. To the south of Sage's Ravine and at the altitude of the summit plain, opens a wide bench fully a quarter of a mile in width with the Everett Schists rising abruptly from its western edge in Mt. Bear. To the east of it are thin caps of Everett Schist, then small outcrops of graphitic schists, alternating for a short distance with garnetiferous and staurolitic schists, and finally the latter occurs alone, clearly showing that in the bench and for some distance east of it, the thin bed of graphitic schist lies at the surface. These relations are exhibited in section G′ of Fig. 2. Still farther south this bench is extended into a broad swampy tract on the two sides of which the two schist horizons are shown in outcrops, the garnetiferous rock being on the east and the other schist on the west. This swampy plain outlining the area occupied by the graphitic belt, crosses the north and south Mt. Riga road just north of Mt. Riga (Bald Peak), its northern and southern limits being marked by sharp turns in the road and abrupt rises in the land, as well as by outcrops of the two schist horizons. In the almost continuous areas of exposures in the vicinity of the Mt. Riga Lakes, its course is carved out sharply though the rock is not found in outcrop. Beyond South Pond the belt narrows and begins to be followed with difficulty. The graphitic rock has been found in outcrop in the bed of a stream flowing toward Mt. Riga Station. Farther down this stream is joined by another from the east flank of Mt. Thorpe, containing likewise a belt of graphitic schists (here calcareous) in contact with garnetiferous rock on the west. This belt of graphitic rock is soon cut off to the south, but it is found to join the main valley through a depression of the ridge to the north-

east of Mt. Thorpe, whence it continues northward as a transitional zone between the valley limestone and the Everett Schist. The rock of Mt. Thorpe is filled with garnets, and the area of schist east of the easterly branch of the stream has also abundant garnets, though they have only been found at some distance from the graphitic rock. Between the two forks of this stream, the upper schist rests as in a saddle, its southern termination being a small triangular hill. The southeastern portion of the map, which exhibits areal and structural features of much interest, will receive fuller treatment in another paper, which will deal with the structure of the area to the southeast of Mt. Washington.

Method of Constructing Sections.—The lines of sections have been made as nearly as possible perpendicular to the strike of the strata. The strike has been obtained either by actual measurement with the compass at the locality, or from the directions of the boundaries of horizons. The curvings of the section lines must therefore indicate, either that the crest or trough lines are inclined (pitch) or that the flexures are of variable width. To the southward of section E the average pitch is found to be northward, as shown by the areal relations, and as indicated in the steep southern and gradual northern slopes of the "Lion's Head."[1] To the north of section E the convexity of the section lines towards the south is explained both by southerly pitch and by a greater compression of the flexures in the northern portion. Southerly pitch is suggested by the topography of Mts. Everett and Undine, as well as by the pitching trough and crest lines of coarse corrugations on the slope that rises at the south end of Guilder Hollow (cf. reference to Dale below). These facts when taken in connection with the sections (Plate IV), show the mountain to have a general basin structure.

The determination of the dip is made with great difficulty within the area studied, since the lamination indicative of the plane of bedding is often obscured or even obliterated by subse-

[1] For the detection of pitch by the contour of an elevation I am indebted to Professor Pumpelly for suggestions. He was, I think, the first to discover that these contours betray in an important manner the inclination of the trough and crest lines of folds.

quently induced cleavage structure. In this particular the problems have been essentially those which were encountered in the Greylock area, and similar criteria have been made use of to distinguish the planes of stratification.[1] Hence with the exception of those localities where contacts of the different rocks are exposed, dip observations have been possible at only a few localities where definite plications could be made out.

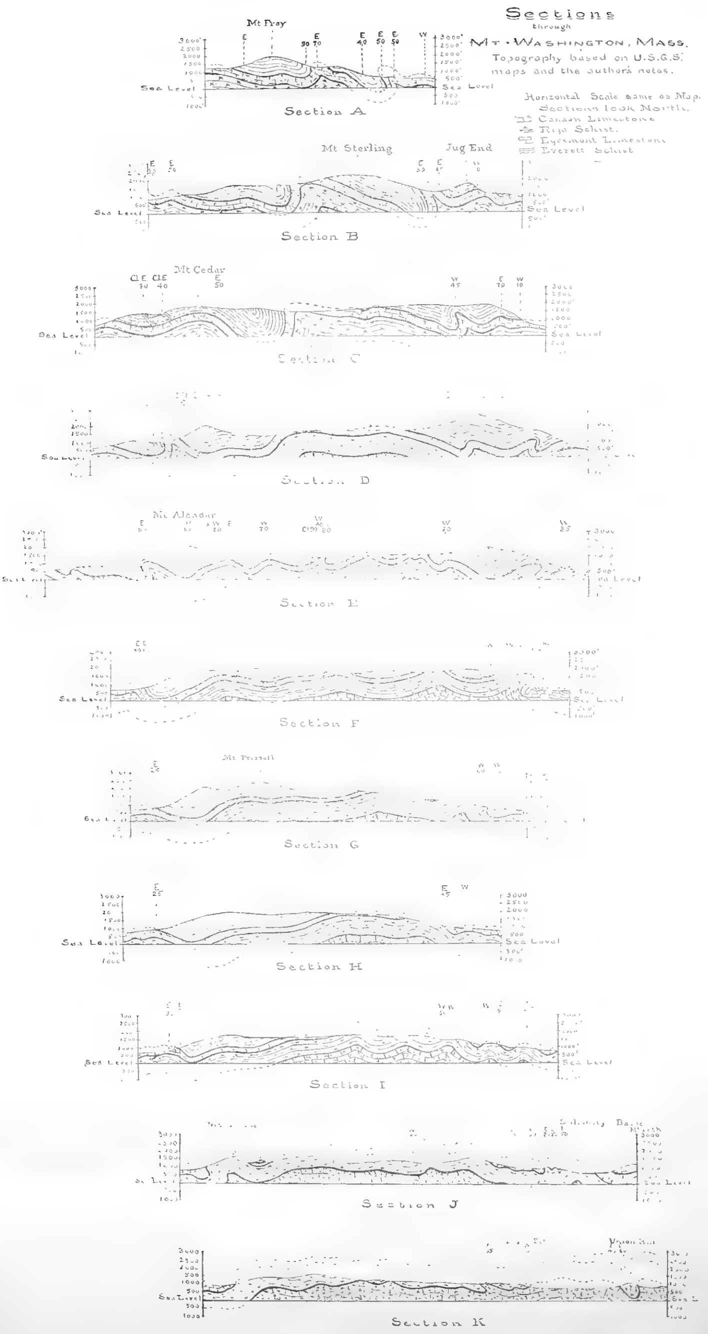
In the absence of dip observations, the sequence being known, many structural facts have been deduced from the areal relations of the several horizons. Next in importance as a method of determining structure is the interpretation of topographical features. It is by application of all of these methods, whose relative importance is expressed by the order in which they have been mentioned, that the sections have been constructed.

The longitudinal section (Fig. 3) which passes through the mountain in a general north and south direction, nearly at right angles to the cross sections just described, is constructed to show how the northerly pitch of the southern portion of the mountain carries the Canaan Dolomite and the Riga Schist so low that they do not appear again to the northward, for although the pitch in the northern part of the area is southerly, it is not sufficient to entirely counteract the very considerable northerly pitch of the southern portions of the mass.

Structure of the Mountain.—The sections show that the southern portion of the mountain is a geo-anticlinal in the Riga Schist, probably with moderate minor folds tolerably symmetrical. Within the core of this anticlinal is the Canaan Dolomite, which appears from under the schist to the southeast of the

[1] An extensive study of the subject of secondary cleavage as it is met with in the Greylock area, has been made by Mr. T. Nelson Dale, and will appear in full in a monograph by Professor Pumpelly on the Geology of the Green Mountains. A summary of his observations and conclusions is contained in the American Geologist for July, 1891. Mr. Dale has also published a paper entitled, "On Plicated Cleavage-Foliation," in the American Journal of Science for April, 1892. As the writer assisted Mr. Dale during a portion of the field investigation, he became familiar with the structures there exhibited, as he did later also in independent work in the northern stretch of the Taconic Range west of Williamstown.

PLATE IV


Sections
through
Mt. Washington, Mass.
Topography based on U.S.G.S. maps and the author's notes.
Horizontal Scale same as Map.
Sections look North.
Canaan Limestone
Riga Schist
Egremont Limestone
Everett Schist
Mt Fray
Section A
Mt Sterling
Jug End
Section B
Mt Cedar
Section C
Section D
Section E
Section F
Section G
Section H
Section I
Section J
Section K
Sea Level

mountain mass. Proceeding northward, one of the minor synclinals in the western limb of the anticlinorium increases in depth and width by a northerly pitch of its trough line, so as to show at the surface, first, the Egremont Limestone, and then more and more of the Everett Schist. The eastern limb of the anticlinal has, in consequence, been narrowed, then compressed and overturned, until east of Mt. Race its axis[1] inclines westward about 35 degrees. The northerly pitch of its crest line carries it continually deeper, until finally it disappears beneath the limestone on the east flank of Mt. Race (cf. Fig. 1). By this process the anticlinorium of the southern portion has been developed in the central portion into a compound fold consisting of two deeply corrugated synclinals (eastern and western schist ridges) and a central corrugated anticilina, which brings the limestone to the surface in the central plain. Proceeding northward still, the flexures sharpen and deepen and become reversed, much as Professor Dana has described. This narrowing of the folds contracts the mountain at its north end, and the succeeding southerly pitching crest and trough lines bring the limestone higher and higher until the overlying schist disappears altogether. To facilitate the comparison of the flexures, Fig. 4 is introduced, the curves being those of the contact of the Egremont Limestone and the Everett Schist as developed in the series of sections. The map, as well as the sections, show that the small schist ridges in the limestone near Salisbury are mainly infolded Riga Schist with the axes of the folds inclined eastward.

Variable Thickness of the Egremont Limestone.—The upper limestone of Mt. Washington forms the

Fig. 3. Longitudinal section through Mt. Washington.

[1] In this paper the term "axis" is used for the axial-plane bisecting a flexure, and never for the crest line or trough line. Cf. Margerie et Heim, Les dislocations de l' écorce terrestre. Zürich, 1888, p. 53.

western part of the great belt which Professor Dana has mapped in this section of Berkshire county. While it has not been found possible to accurately measure its thickness, it may be safely stated that the thickness never exceeds 600 to 800 feet, and that the beds thin out toward the south end of the mountain. They

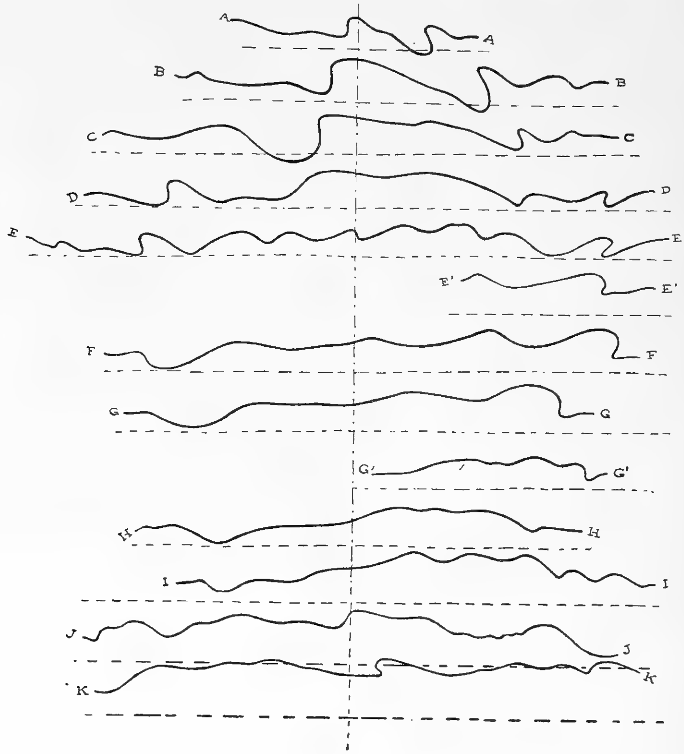


FIG. 4. Series of curves showing the probable form of the flexures in the rocks of Mt. Washington.

also thin out toward the center of the mass from either side. The minimum thickness in the southern portion of the area is probably something less than 100 feet. The general truth of this statement is borne out by an examination of the map and sections (Sage's Ravine, Bear Rock Falls, etc.) As the limestones do not again appear on the southeast flank of the Cornwall-Sharon core of older rocks, it is probable this horizon never

extended much beyond its present limit in a southerly direction. As the bed thins out it becomes more graphitic, indicating also that the conditions attending its formation had here some peculiar local characters.

Metamorphic Character of the Rocks as Indicated by Microscopic Studies.—The microscopic examination of thin sections of rocks from Mt. Washington shows clearly that they are strongly metamorphosed clastics. Evidence has been deduced from the secondary growths of feldspars, garnets, and tourmalines, as well as from the relations of the different metamorphic minerals to one another, to show that the orographic forces to which these minerals owe their development, operated in several more or less distinct periods.[1]

Summary and Conclusions.—What has been set forth in the preceding pages agrees well with Professor Dana's views so far as the northern portion of the area is concerned. In the southern and central portions, however, where the areal and structural relations are more obscure, I have arrived at very different conclusions. This has been due, not to the discovery of errors in Professor Dana's observations, which have been in the main confirmed, but to the collection of a larger number of observations and to the application of some structural principles which were not made use of in his study. A glance at the map will show how perfectly the belt of Egremont Limestone which crosses the southern portion of the mountain, is concealed where it meets the valleys. This belt, the discovery of which furnished a key to the structure, is not at first apparent to the geologist, because at its ends the boundaries of the Riga Schist coincide closely in direction with and form an extension of the boundaries of the Everett Schist.

To summarize briefly the results which have been discussed in the foregoing, the Mt. Washington series consists of four members, which in order of age are as follows: 1) Canaan Dolomite, 2) Riga Schist, 3) Egremont Limestone, and, 4)

[1] Phases in the Metamorphism of the Schists of Southern Berkshire: WM. H. HOBBS. Bull. Geol. Soc. Am., vol. iv., pp. 167–178, pl. 3.

Everett Schist. A somewhat striking lithological distinction, which has been valuable for purposes of identification, is found to separate the two schist horizons, the Everett Schist being entirely free from garnet and staurolite, while the Riga Schist usually (though not always) contains macroscopic crystals of one or both of them. The older rocks are found in the southern portion of the area, a general northerly pitch carrying them successively below the surface as we proceed northward, until at the north end of the mountain we find the upper two members of the series only.

The structure of the mass may be summarized by stating that the beds have been thrown into corrugated folds which seem to have moderate, tolerably symmetrical corrugations at the south end of the mountain, but these corrugations deepen and become frequently overturned as we proceed northward. In the eastern portion of the area the axes of the reversed folds is generally westward. At the extreme south, the structure is a geo-anticlinal, but this develops in the central and northern parts of the area into a geo-synclinal owing to the continued disproportionate deepening and widening of one of its minor western corrugations. The general pitch of the beds is north. A less important southerly pitch which characterizes the northern portion of the area, in combination with the general synclinal structure in cross sections, gives to all the mountain except its extreme southern portion a basin-like character. The rocks are throughout strongly metamorphosed clastics, the orographic disturbances to which they owe their marked crystalline character and porphyritic crystals having operated in several distinct periods. The Egremont Limestone shows a marked diminution in thickness as we proceed southward in the area until it almost disappears. Throughout the mountain plain it is greatly modified, being either a micaceous limestone or calcareous mica schist, or a graphitic schist. The graphitic rock is most developed near the schist contacts and in the southern portion is the only representative of the limestone.

Wm. H. Hobbs.

University of Wisconsin, Madison, Wis.

EDITORIAL.

AT THE recent meeting of the British Association for the Advancement of Science in Nottingham, the section devoted to geology was perhaps the busiest department of the association. Contributions covering nearly all phases of the science crowded the time allotted to the reading of papers. Among them petrology held a prominent position, owing to the eminent character of the president of the section, and to his successful labors in this branch of geology. Mr. Teall based his presidential address upon the data furnished by petrological research, which, to his thinking, lend additional strength to the uniformitarian doctrines of Hutton. By a variety of illustrations he showed the identity of ancient and modern rocks, whether sedimentary, igneous, or metamorphic, and inferred a similarity of physical conditions attending their formation. He emphasized the high degree of differentiation of organic life at the time when the first Cambrian strata were deposited, and maintained that the crystalline schists of earlier age, so far as we have yet become acquainted with them, do not contain the records of the early stages of the planets' history. They can not be considered to represent the primitive crust of the earth. His testimony as to the identity of the volcanic lavas erupted in Paleozoic and Tertiary times in Great Britain, both as regards their structure and composition, allowance being made for subsequent alteration, is significant. It shows that in this region, through a long succession of ages, the groups of rock magmas developed in different periods of volcanic activity have been similar, and that the essential character of the petrographical province did not change.

Sir Archibald Geikie's paper, "On Structures in Eruptive Bosses which Resemble those of Ancient Gneisses," was a valuable

contribution to the study of gneissic structure, since it showed the possibility of a part, at least, of the banding in these rocks being due to a primary banding of igneous masses through some process of segregation or through differentiation of the magma into layers. A parallel banding of igneous rocks in the neighborhood of a plane of contact has been known, but its magnitude is generally inconsiderable. The structure in the gabbro on the Isle of Skye, however, which was described by Geikie, is on a large scale, and without apparent relation to a plane of contact. No attempt was made to suggest a cause for such a mode of segregation, since the study of the locality where it is best developed is not yet completed.

Prof. Brögger's paper, "On the Genetic Relations of the Basic Eruptive Rocks of Gran, Christiania Region," presented an array of facts with regard to the differentiation of rock magmas. By means of chemical analyses and field observations he showed that basic magmas of like composition in neighboring localities had separated into pairs of magmas, which were quite unlike one another chemically; producing dissimilar pairs of rocks. This proves that a given magma may differentiate in more than one manner, according to circumstances. The entire paper is to appear in the Quarterly Journal of the Geological Society.

Mr. Harker discussed the question of magmatic concentration, or differentiation, with reference to its probable cause, and pointed out what seemed to him obstacles to the application of Soret's principle. He suggested that a more probable explanation would be found in Berthelot's principle, or that of maximum dissipativity. The applicability of Soret's principle to the differentiation of magmas is also assailed by Prof. Bäckström in an article to appear in the next number of this JOURNAL, and the principle of liquation advocated. While it is quite probable that all of the phenomena of segregation and differentiation may not be accounted for by one law of diffusion dependent on osmotic pressure, and while this law finds its most perfect realization in the most dilute solutions, and while certain separations of rock magma may take place near the point of saturation, still it can

not be denied that rock magmas at times are known to attain extreme liquidity. Moreover, there must undoubtedly be a number of different physical causes at work conjointly, each of which may preponderate under favorable conditions, so that it is quite probable that no single process will be found adequate to explain all the phenomena in question.

It is interesting to observe that, while the majority of petrologists are engaged in studying the evidences of differentiation of molten rock magmas, the theory of magmatic synthesis proposed by Bunsen is not being wholly neglected. From the nature of a portion of the evidence it is possible to frame diametrically opposite hypotheses, but when all of the conditions are taken into account it would seem that but one of the hypotheses can have a general or far-reaching application. Prof. Sollas's paper, "On the Origin of Intermediate Varieties of Igneous Rocks by Intrusion and Admixture, as Observed at Barnavave, Carlingford," demonstrated how intimately the material of an acid molten magma may penetrate the interstices of a highly fractured rock, in this case basic; the delicate veins thinning to almost microscopic dimensions. Instances of this kind are well known. The assumption, however, that this process has taken place to a very considerable extent, and has produced bodies of rock of intermediate composition, seems to ignore the probable physical conditions under which rock magmas are irrupted, and also the geological probabilities of such things happening. Thus there may be no defect in the logic of the assumption as an abstract idea, but there may be little or no probability of its ever taking place to a considerable extent in nature.

Other petrological papers were presented by Prof. Sollas, Mr. Watts, Dr. Johnston-Lavis, and an interesting account of the volcanic phenomena of Japan was given by Prof. Milne, and illustrated by lantern slides. It cannot be out of place, for one who has been fortunate enough to have been a guest of the Association, to express a high appreciation of the honor, as well as of the generous social hospitality which has become a distinguishing characteristic of these meetings. J. P. I.

Reviews.

Correlation Papers. The Newark System. By Israel Cook Russell. Bulletin 85, U. S. Geological Survey. Washington, 1892.

This Bulletin adds another number to the list of invaluable correlation papers, prepared especially for the Geological Survey, but of the greatest service to all professional geologists and advanced students alike. Prof. Russell's paper is of exceptional completeness from the bibliographical side; its index is a marvel of minute reference; every author's name is followed by a complete list of his writings, the more important ones being analyzed; every locality noticed in any paper is indexed separately, with reference to the place of its mention; occurrences of sandstone, shale, conglomerate and trap are catalogued under these headings. Immediate reference may thus be made to any desired item concerning the Newark system, excepting the fossils, which, for some reason, are not indexed under their names, but only through the authors who have described them.

The chief headings of the text are: Nomenclature, area, lithology and stratigraphy, conditions of deposition, life records, associated igneous rocks, deformation, former extent, correlation and summary. A good number of maps serve to guide the reader to the easy understanding of the several areas into which the formation is divided. I can only comment on a few of these subjects.

Professor Russell has done good service in the fourth headings in showing the incompleteness of the evidence on which glacial action has been argued as an agency in the deposition of the formation. Near the margin of several of the Newark areas, heavy conglomerates, containing boulders up to four or five feet in diameter, are known at various localities; and although none of these deposits are unstratified, they have frequently been appealed to as evidence of glacial action. But none of the boulders are scratched or notably angular; all of them are, as far as known, deposited near the shore of their time; all of them are systematically interbedded with ordinary aqueous deposits. Cer-

tainly they are not unaltered glacial deposits; and to assume that they are derived from such is to imply that no agency but glaciers is competent to move boulders of several feet in diameter. Russell refers to the occurrence of large angular rock masses on the alluvial fans of the arid regions at a distance of two or three miles from their source, to show that the movement of large boulders may take place under subaërial conditions; he cites the absence of ice-borne boulders among the finer strata of the Newark deposits; and he argues a relatively warm, not a cold climate, from the prevailingly red color of the formation and from the character of the fossils. Emerson has detected large boulders in certain basal beds of the sandstones in Northern Massachusetts, demonstrably close to their source, and not in the least indicative of glacial transportation. Indeed, to conclude that glacial action occurred at sea level during the period of Newark deposition simply from the coarse nature of certain marginal conglomerates, is to adopt an open alternative instead of a closed demonstration as a guide to belief.

Another line of evidence may be introduced against Fountaine's argument that the Newark conglomerates of Virginia were derived from glaciers which descended from the Appalachian mountains of that time. Local glaciers could originate in that latitude only on lofty mountains, from which they might descend to sea level, much as those of New Zealand do now. But the evidence gathered from the outline of the under border of the Newark areas does not at all favor the idea that they closely adjoined lofty mountains. If such had been the form of the surface whose submergence allowed the accumulation of the Newark sediments, their under border must have been extremely irregular; the Newark waters must have rounded many a bold promontory and penetrated many a deep bay. The basal sediments accumulated along so sinuous a water margin should now show some indication of these promontories and bays. They should be distributed much in the way that the Permian breccias of Wales lie around their once buried and now resurrected mountains, and thus show their origin on an extremely irregular coast. But as far as the basal beds of the Newark system have been studied out, they do not indicate that the surface on which they lie possessed any great relief at the time of their deposition. Whatever deformation it had previously suffered, whatever mountainous heights this deformation produced, the action of erosion had in pre-Newark time carried away enough material to some unknown goal

to leave a surface of only moderate inequality; by no means of such inequality as would gather snow fields on its higher levels, and shed long glaciers down its valleys into the Piedmont seas.

The prevailing red color of the Newark strata is also adduced by Russell as indicative of a relatively warm climate, as contrasted to a glacial climate. To this might be added that the slow subaërial decay, from which red soils and sediments seem to be derived, is inconsistent with the conditions of decay on lofty mountains, from which the detritus is shed rapidly, leaving a relatively large surface of bare rocks; while it is accordant with the idea of a well denuded region, from which further denudation carries material slowly.

In examining the structural relations of the igneous rocks, it is noticeable that little success has as yet attended the efforts of observers southwest of the Delaware to distinguish between the intrusive and extrusive origin of their trap sheets. It would seem from this that the scouring of the decayed surface of the Newark belts by Pleistocene glacial action has been an advantage to the geologist of to-day in New Jersey, Connecticut and Massachusetts; but an advantage that is frequently offset by the sheets of drift which obscure or conceal so many of the weaker strata in the Connecticut valley. I believe that Connecticut alone has yielded a greater number of localities where the contact of the sandstones on the trap sheets can be actually seen, and from which good hand specimens can be secured, than all the areas beyond the Hudson. It may be noted that the map of the New York-Virginia Newark area, compiled by Russell from such data as he could gather together, does not give a correct impression of the crescentic trap ridges of eastern Pennsylvania. I have only examined a small part of that district, but from what was seen and from the topographic maps of the Perkiomen drainage area, surveyed by the Philadelphia water commissioners for a proposed new water supply, I think that an accurate geological map of the district will disclose a more systematic arrangement of forms than now appears.[1]

The deformation of the Newark areas has been a subject for much discussion already, and it will doubtless furnish as much more in the future. Before it can be successfully deciphered, the stratigraphic succession of the system must be made out; and that has not been generally done, as may be seen from Russell's chapter on lithology and

[1] Since writing the above, I have seen the new geological map of Pennsylvania, on which the curved trap sheets are clearly shown.

stratigraphy; in which the various kinds of rocks are enumerated, but in which their succession and thickness is not stated. The difficulty of the problem lies in the monotony of the strata, and in the doubt in many cases as the origin of the trap sheets. Whatever success has yet been gained in solving this problem, it has come chiefly through the aid given by the old lava flows, and only secondarily through ordinary stratigraphic methods. In Pennsylvania and further south, no complete stratigraphic correlations have yet been established; mainly, as has has been stated above, because the trap sheets there are not yet well deciphered. In New Jersey the discrimination between intrusive and extrusive sheets has been well accomplished, but doubt is felt as to the location of fault lines by which they are dislocated, this doubt resulting from the uncertainty as to the reappearance of identical sandstone strata or trap flows. It is only in the Connecticut valley that the variety of trap sheets and associated sedimentary beds is such as to make the demonstration of faults complete. Here, over a considerable share of the area, the stratigraphic succession is made out with much certainty; and the lines of dislocation are determined with sufficient precision. At the same time certain fossiliferous beds, rare in the formation as a whole, and therefore of all the more value in defining horizons, have been traced for thirty or more miles inland from Long Island Sound; and their dislocations agreeably confirm the conclusions previously reached as to the faulting of the trap sheets.

Like so many other features of this peculiar system of rocks, its style of deformation is exceptional. It is nowhere folded in the ordinary manner; where curvature of bedding appears, it is of such character as to give crescentic outlines to the beveled edges of the strata now visible. The formation is, as a rule, tilted over to a rather regular monoclinal attitude; but while the earlier conceptions of its structure implied that the monocline was practically uninterrupted, the later studies show it to be complicated by numerous faults, traversing the mass in various directions, and as a rule systematically arranged, although the control of the system is obscure. One thing is clear: the faults penetrate the crystalline foundation on which the Newark beds lie; they are not dislocations within the Newark beds alone; indeed, it almost seems fair to say that the dislocating forces were indifferent to the cover of Newark beds, and that their action was chiefly expended on a much deeper mass of rocks

The original extent of the Newark areas has been much discussed,

and Mr. Russell, some years ago, espoused the idea that their present surface was a comparatively small part of their original basins. This matter is essentially indeterminate at present; but the valid evidence of great post-Newark erosion disposes me to accept almost any measure of former extension of the system that may be required by reasonable argument. At first, the mind halts before the supposition that vast masses have been uplifted and worn away in the ages since the date of the Newark deposition, but the evidence of vast denudation in that interval is now so complete that it no longer seems warrantable to withhold belief in the "broad terrane hypothesis," either from its extravagant erosion of rock masses, or from an apparent insufficiency of time for such extravagance.

On the other hand, while it seems likely that there was some connection between the several separate Newark areas, because their fauna and flora are so similar, it does not seem necessary to conclude that all the space between the Connecticut and the New Jersey areas was once overspread by Newark strata. It may have been. There was time enough during the Newark deposition to furnish material for such a cover; and there has been time enough since then to wear it away; but still there is no direct evidence that it existed. The original boundaries of the formation are very vaguely defined.

Noticing that a greater definiteness of results has been gained in the Connecticut valley than in the other Newark areas, it is evident that the physical conditions of origin of the trap sheets in the southern areas deserve the closest scrutiny. If they prove to be intrusive sheets, they are of little structural value. But if they are proved to be extrusive, they may then be treated as conformable members of the stratified series, and thus a key to the general attitude of the system is gained. After this step, the detection of sequences of strata, including extrusive trap sheets with the aqueous sediments, is of next importance, as by this means faults may be located, and thus some advance made in the general reconstruction of the formation.

But even where best studied out, it is likely that the cross sections by which underground structure is represented are hardly more than parodies on the facts; so insufficient are the opportunities for the discovery of deep internal structures. A close knowledge of the system seems beyond reasonable expectation.

W. M. Davis.

Harvard College, November, 1893.

Text-book of Comparative Geology. By E. KAYSER, Ph.D. Translated and edited by PHILIP LAKE. Pp. xii, 426. Swan, Sonnenschein & Co., London. (Macmillan).

The translation of Dr. Kayser's book is a welcome addition to the literature of geology in English. Its title is fairly definitive. It is an attempt to bring together, or to set in their proper relations, the results of geological investigation conducted in the various parts of the world. The volume is too brief to allow this to be carried out in great detail. The abbreviation has been effected in part by the omission, or by no more than the merest mention, of results reached in extra-European countries. This is particularly true with that part of the volume which deals with the post-Paleozoic formations. While at first thought this might seem to detract from the value of the volume for American students, we think on the whole it is an advantage instead, if omissions were necessary. Data concerning American geology are more easily accessible to American students than data concerning European geology, which this volume measurably supplies. The volume will find its chief use in America as a convenient reference book of European geology, and as such it should be widely distributed. Its abundance of tables, showing the relations of the subdivisions of the various systems in different countries, so far as they are made out, are especially convenient for general reference.

At several points in the volume there is a noticeable tendency to make unqualified statements where qualified statements would seem to us better. A case in point is the unqualified denial of the organic character of the Eozoon. It is true in most cases, where positive conclusions are asserted, that they represent the best conclusions of the present day, but in some cases they seem to us to represent probable or qualified or tentative conclusions, not demonstrated or absolute or final ones.

All pre-Cambrian rocks are represented as Archean, though the length of Archean time is stated to be so great that the beginning of the Cambrian "may be considered as comparatively a recent event." In spite of this recognition of the importance of the Archean, but fourteen pages are devoted to its consideration. Although different systems are not recognized in the pre-Cambrian rocks, the diversity of origin of different parts of the group is distinctly recognized. The author is inclined to attach less weight to the existence of limestone and graphite in the Archean rocks, as indications of life, than would

most geologists. He thinks that the strongest evidence for the existence of life in pre-Cambrian time is the high organization of the Cambrian fauna. While geologists will be ready to assent to the strength of this last argument, they will hardly be ready to regard it as the only strong reason for belief in pre-Cambrian life. To the very considerable number of fossil forms already found in pre-Cambrian rocks no reference is made.

The important question of the origin of the Archean is rather briefly dismissed. The discussion touching this question is much less full and much less satisfactory than that of Prof. Van Hise, recently published.[1] Indeed, had Prof. Van Hise's discussion been published before Dr. Kayser's treatise, the latter author might have found a way out of some of the difficulties which seem to lie in his mind concerning the origin of the Archean.

An excellent feature of the book is the prefacing of the discussion of each system by a short account of the origin and history of its differentiation from underlying and overlying systems. Each system is discussed under the general heads of — 1) Distribution and development; 2) Paleontology. Under the first head, it could have been wished that the structural relations of the systems had been more uniformly and sharply brought out. Such clear statements as that concerning the North American Devonian system, that it rests "conformably and without break on the Silurian, and is covered conformably by the Carboniferous" (page 111), are not always to be found. Where knowledge does not permit such positive statements, definite statements representing the degree of present knowledge would have been welcome. So, too, the relations of faunal and stratigraphical breaks are not always so clearly set forth as could have been desired in a text-book.

In the discussion of the Permian system, Dr. Kayser brings out the fact of wide-spread conglomerate formations (India, Victoria, Brazil, South Africa) in tropical latitudes and the southern hemisphere, which sometimes contain polished and striated stones very like those of glacial formations of later date. In Africa the Dwyka conglomerate rests on rock, the upper surface of which is smoothed and striated like rock beneath the modern glacial drift. Dr. Kayser indicates that the belief that these Permian conglomerate beds are of glacial origin has gradually gained ground. The flora succeeding the conglomer-

[1] Bulletin of the U. S. Geol. Survey, No. 86.

ate in Africa, South Asia and Australia is characterized by Mesozoic types. This change is believed by many to have been brought about by the cold climate which was the determining cause of the conglomerate beds. Blanford and Waagen go further and connect the decline of the marine Paleozoic types with the cold climate of the end of the Paleozoic.

In the discussion of the Mesozoic and Neozoic there is scarcely any reference to American geology. In connection with the discussion of Pleistocene geology, two glacial epochs are recognized. The author inclines to the eolian hypothesis for the origin of loess.

Both the physical and paleontological phases of the subjects discussed in the volume are illustrated by numerous figures, the former rather less fully than the latter. A series of maps, showing the distribution and relations of the systems described, would have enhanced the value of the volume which is still great without them.

ROLLIN D. SALISBURY.

Iowa Geological Survey. Vol. I. First Annual Report, 1892. SAMUEL CALVIN, State Geologist, Des Moines, 1893. 8vo, 472 pp., 10 plates and 26 figures.

IN addition to brief administrative reports, the first report of Iowa's third survey contains papers by S. Calvin, C. R. Keyes, Assistant State Geologist, S. W. Beyer, H. F. Bain and G. L. Houser.

The introductory paper by Mr. Keyes, on the Geological Formations of Iowa, is a summary of present knowledge of the various formations occurring within the limits of the state. The writer has availed himself of the various studies made of these rocks in recent years, and the result is shown in an improved classification over that of preceding surveys. While all the formations have come under careful study, the most notable progress is shown to have been made in the classification of the Devonian, the Carboniferous and the Cretaceous.

Investigations in northwestern Iowa have brought to light the presence of undoubted eruptive rocks at no great depth below the surface. In Mr. Beyer's paper are given the details relating to the discovery of typical quartz-prophyry, interbedded with sandstone and gravel, in a deep well at Hull, Iowa. The discovery by Culver and Hobbs of eruptive rock within the Sioux quartzite in southeastern

Dakota is referred to, and, following Hall, White, and Irving, the conclusion is drawn that the Sioux quartzite is the oldest formation in the state. Some familiar names have disappeared from the geological section, and their places are assumed by newer but more appropriate terms, as, for example, Oneota for Lower Magnesian, St. Croix for Potsdam, while Hamilton is represented by four names applied to as many subdivisions. The term Augusta is given to the terranes including the Warsaw, Keokuk and Burlington, in place of William's term Osage which is discarded as inapplicable. The Warsaw beds of Hall are here included with the Keokuk, and the term Warsaw dropped. An error occurs in the definition of the St. Louis limestone on page 72, where it is asserted that the brecciated limestone constitutes the base of the beds in Iowa. This is the case only along the extreme margin of the beds. Seaward from the old shore line, as shown along the Des Moines in Van Buren county, the basal member consists of a brown, magnesian limestone in fairly regular, more or less undulating beds. The texture is sometimes nodular and sandy. In thickness the formation varies from five to fifteen feet or more.

The structure of the coal measures is treated in considerable detail, and emphasis is given to conclusions based largely upon Mr. Keyes' investigations in Iowa. These rocks are included in two stages, the lower or Des Moines, and the upper or Missouri formation, White's middle division being discarded. These are not considered two distinct formations in the sense that the lower was deposited prior to the laying down of the upper—the view commonly entertained—but the two were formed contemporaneously, the former as a marginal or shore formation, and the latter as its deep or open sea correlative. The view here advanced seems to be a modification of that held by Winslow. The conditions of deposition were evidently those of a slowly sinking shore, and the marginal deposits practically underlie the open sea formation though not necessarily much older ; hence the terms lower and upper are retained, though emphasis is given to their general contemporaneity. The summary of Professor Calvin's researches on the Devonian and Cretaceous rocks shows a marked advance in the knowledge of these formations.

The classification of Iowa rocks, given by the different surveys, is here presented for comparison :

HALL'S REPORT, 1858.

- Quaternary.
  - Alluvium.
  - Drift.
- [illegible] Cretaceous.
  - Presence in Iowa asserted, but rocks not described.
  - Given on Owen's authority.
- Permian ?—Gypsum beds.
- Carboniferous.
  - Coal Measures.
  - Carboniferous limestone.
    - Kaskaskia (not present).
    - Ferruginous sandstone (not present).
    - St. Louis limestone.
    - Warsaw.
    - Keokuk.
    - Burlington.
- Devonian.
  - Chemung group.
  - Hamilton group.
  - Upper Helderberg limestone.
- Upper Silurian.
  - Le Claire limestone.
  - Niagara limestone.
- Lower Silurian.
  - Hudson River group.
  - Galena limestone.
  - Trenton limestone.
  - Black River and Birdseye limestone.
  - St. Peter's sandstone.
  - Calciferous sandstone.
  - Potsdam sandstone.
- Huronian—Sioux Quartzite—1866.

WHITE'S REPORT, 1870.

- Post Tertiary.
  - Alluvium.
  - Bluff.
  - Drift.
    - Altered.
- Lower Cretaceous.
  - Inoceramus beds.
  - Woodbury sandstone and shale.
  - Nishnabotna sandstone.
- Carboniferous.
  - Coal Measures.
    - Upper.
    - Middle.
    - Lower.
  - Sub-Carboniferous.
    - Chester (not present).
    - St. Louis.
    - Keokuk.
    - Burlington.
    - Kinderhook.
- Devonian—Hamilton limestone and shale.
- Upper Silurian—Niagara limestone.
- Lower Silurian.
  - Maquoketa.
  - Galena.
  - Trenton.
  - St. Peters.
  - Lower Magnesian.
  - Potsdam.
- Huronian?—Sioux quartzite.

CALVIN & KEYES REPORT, 1892.

- Quaternary.
  - Alluvium.
  - Loess.
  - Drift.
    - Upper till.
    - Lower till.
- Upper Cretaceous.
  - Niobrara.
    - Inoceramus and possibly gypsum beds, and Nishnabotna sandstone.
  - Fort Benton.
  - Dakota.
    - Woodbury shale, and possibly the Nishnabotna sandstone
- Carbonoiferus.
  - Upper Carboniferous or Pennsylvania Series.
    - Missouri Stage.
    - Des Moines Stage.
  - Lower Carboniferous or Mississippian.
    - Kaskaskia (or Chester) (not present).
    - St. Louis.
    - Augusta
      - Keokuk.
      - Burlington.
    - Kinderhook.
      - Chouteau lm.
      - Hannibal sh.
      - Louisiana lm.
- Devonian.
  - Lime Creek shale.
  - Montpelier sandstone.
  - Cedar Valley limestone.
  - Independence shale.
- Upper Silurian.
  - Le Claire limestone.
  - Niagara limestone.
- Lower Silurian.
  - Maquoketa.
  - Galena.
  - Trenton.
  - St. Peters.
  - Oneota.
- Upper Cambrian—St. Croix.
- Algonkian—Sioux quartzite.

Other papers by Mr. Keyes are: "Annotated Catalogue of Minerals," and "Bibliography of Iowa Geology."

Professor Calvin's paper is devoted to the Cretaceous deposits of Plymouth and Woodbury counties. In the region studied these beds are found to be sharply divisible lithologically into two divisions, a lower consisting of soft sandstones, with bands of hard ferruginous concretionary nodules, and variegated, often parti-colored clays, the latter greatly predominating and resting upon these a white or yellowish chalk, somewhat indurated in places into a soft fissile limestone. The first is White's Woodbury sandstones and shales, and the second is his Inoceramus beds. Following Meek and Hayden, Professor Calvin makes a threefold division of the beds, by drawing a somewhat arbitrary line about forty feet below the base of the Inoceramus beds. The lowest division contains impressions of leaves and a meagre brackish water fauna. This he correlates with the Dakota group. The second or middle division of dark colored calcareous shales, containing marine mollusks, associated with the vertebræ and teeth of bony fishes, and the skeletons of marine saurians, is the Fort Benton group of Meek and Hayden. The upper or Inoceramus beds represent the Niobrara of the same authors. During this epoch the Cretaceous sea had its farthest eastward extension, probably reaching as far as the Mississippi river in northeastern Iowa.

Mr. Beyer's paper is entitled Ancient Lava Flows in the Strata of Northwestern Iowa, and relates to the discovery in a well at Hull, Sioux county, of typical quartz porphyry at a depth of 755 feet. Microscopical study shows it to have a pronounced flow structure, while the quartz crystals show the effects of magmatic corrosion, and, in some cases, fracturing with discordant orientation of the fragments, from which it is inferred that the magma was semi-viscous and under great pressure when the flow took place. In the drilling, the eruptive rock was found to alternate with sandy strata, showing evidence of metamorphism down to 1,200 feet. Two hypotheses are advanced to account for the flows: (1) That they took place in Paleozoic times, perhaps Carboniferous, the lava being periodically poured out over the old sea bottoms; and (2) that the whole series of flows was contemporaneous, and in point of time post-Carboniferous. In this case the intercalations may be regarded as intrusive sheets, following the lines of least resistance and forcing themselves between the strata. Most probability seems to attach to the latter view.

Mr. Bain's paper deals with the distribution and relations of the St. Louis limestone in Mahaska county, where it is shown to have the same irregularity as to thickness and structure as it presents generally in Iowa. To explain the irregularity in the surface of this formation, appeal is made to erosion during Kaskaskia time, when Iowa was a land surface. This would imply a considerable elevation in order to produce the carving, a conclusion not wholly free from doubt. In some localities a sandstone, treated as presumably belonging to the coal measures, rests upon the limestone.

The remaining paper, by Mr. Houser, is devoted to a discussion of some lime-burning dolomites, and dolomitic building stones from the Niagara.

C. H. GORDON.

THE

JOURNAL OF GEOLOGY

NOVEMBER-DECEMBER, 1893.

THE SUPPOSED GLACIATION OF BRAZIL.[1]

THE inquiries I have received from time to time regarding the supposed glaciation of Brazil in Pleistocene times, the doubts sometimes expressed regarding it, and the occasional appeals made to it,[2] induce me to state briefly what I know about the matter.

Strangely enough the errors of Agassiz, Hartt and Belt regarding glaciation in Brazil have been turned to account both by those who have theories that need the support they think the glaciation of Brazil would give them, and also by those who seek by means of these errors to throw discredit on the subject of glacial geology.

I believe the case has been generally dropped by geologists as not proven, but I am confident that no one wishes to ignore the evidence "merely because it runs counter to all his preconceived opinions."[3]

EARLY VIEWS OF AGASSIZ AND HARTT.

When Professor Louis Agassiz made his trip to Brazil in 1865, on board the steamer going out he gave a series of

[1] Advance quotations are made from this article by Dr. Alfred R. Wallace in Nature, Vol. 48, No. 1251, Oct. 19, 1893, 589–590.

[2] The Glacial Nightmare and the Flood, by Sir HENRY H. HOWORTH, London, 1893. MARSDEN MANSON, in the Trans. of the Geol. Soc. of Australasia, I., pt. VI., 155–170, and in the Trans. of the Tech. Soc. of the Pacific Coast, VIII., No. 2, 19. Geological and Solar Climates; their Causes and Variations, by MARSDEN MANSON, University of California, May, 1893. Ragnarok, by IGNATIUS DONELLY.

[3] WALLACE: Nature, Vol. II., 1880, 511.

lectures in which he suggested to his assistants the possibility of the South American continent having been glaciated, and reminded them that this was one of the important subjects for their investigation.[1]

I subsequently learned from Professor Hartt, who was one of the assistants, that these lectures prepared them to be convinced that glaciation had taken place in Brazil, though he himself was rather inclined to believe otherwise.

Mrs. Agassiz's book shows throughout how Professor Agassiz found on every hand, from the time he landed in Brazil till he left there, what he regarded as evidences of glacial action. In the mountains about Rio de Janeiro he found erratic boulders (pp. 86 *et seq.*); at Ereré, in the Amazon valley, he found "the only genuine erratic boulders I have seen in the whole length of the Amazon valley," (p. 418); he declared that "il n'y a pas trace des terrains tertiaires"[2] in that region, while the horizontal sediments of that valley he explained as silts thrown down in cold glacial waters behind a vast terminal moraine that stretched across the mouth of the valley (p. 426), and of which the island of Marajo was supposed to be a remnant; the table-topped hills he explained as the remnants of sediments left when this great dam broke, and the waters swept the greater part of the beds out to sea.

The lateral moraine on the south side of this great glacier he expected to find in the interior of Ceará (p. 447-8); he went to Ceará, and found at Pacatúba, near the coast, what he regarded as glacial phenomena "as legible as any of the valleys of Maine,

[1] A Journey to Brazil, by Professor and Mrs. LOUIS AGASSIZ, Boston, 1868, 15. In Mrs. AGASSIZ's Life and Correspondence of Louis Agassiz, Boston, 1886, II., 633, it is further stated that Agassiz was confirmed "in his preconceived belief that the glacial period could not have been less than cosmic in its influence."

[2] Bul. de la Soc. Géologique de France, XXIV., 110. In a letter to Élie de Beaumont, he speaks of these beds as loess, but he gives no specific explanation of their formation. Comptes Rendus de l'Acad. des Sciences, 1867, 1269. Professor Agassiz first published his paper on the Physical History of the Amazon valley in the Atlantic Monthly for July and August, 1866; it was also published subsequently in his Geological Sketches, sec. ser. Boston, 1886. II., 153 *et seq.*, and in the Journey to Brazil.

or in those of the valleys of Cumberland in England" (pp. 456, 463).

Naturally enough these views were received in the scientific world with incredulity. As Mr. Wallace remarks, "Prof. Agassiz was thought to be glacier-mad,"[1] but his earlier observations on glaciers had been received with quite as much doubt,[2] so that the doubts have nothing to do with the case one way or the other.

Professor Chas. Fred. Hartt states in his book[3] that he was at first very skeptical about Brazilian glaciation, but that he was finally obliged to yield to the evidence collected by himself, and to confess that Agassiz was right.

It should perhaps be mentioned here, that there is a general impression that when Hartt wrote his book on the geology of Brazil, he had spent several years, and traveled widely in that country, and that the conclusions given by him are the results of all his Brazilian work. This is far from being the case. When he wrote the Geology and Physical Geography of Brazil, he had spent only a year and a half in that country; on his first trip he arrived at Rio de Janeiro, April 23, 1865, and left it on July of the following year;[4] on his second trip, he reached Pará, July 11, 1867,[5] and returned from Rio in September of that year,[6] making in all not more than eighteen months spent in that country up to the time his book went to press. The belief in the glaciation of Brazil, as there expressed, is therefore based upon his earliest and least trustworthy work in that region. Hartt fully recognized this afterwards, and I have often heard him say, "I wish I had known as much about geology when I wrote that book as I know now."

He subsequently made several trips to Brazil; in one to the

[1] Nature, II., 511. LYELL's Principles of Geology, New York, 1889, 1, 466.

[2] Bul. de la Soc. Géol. de France, 1867-8, XXV., 685.

[3] Geology and Physical Geography of Brazil, Boston, 1873, 29.

[4] Agassiz, Journey, 46 and 540.

[5] American Naturalist, I., 648.

[6] Geology and Physical Geography, 201.

Amazon valley he examined the table-topped hills[1] which Agassiz had referred to glacial action, and the boulders he had called "the only genuine erratic boulders" he had seen in the Amazon valley. Already, in 1867, Professor James Orton, who scouts the idea of the glaciation of the Amazonas, had discovered at Pebas, in the supposed glacial sediments, "marine or perhaps rather brackish water Tertiary fossils."[2]

In 1871 Hartt found the supposed erratics of the Amazon valley to be boulders of decomposition derived from trap dikes near at hand, and stated that he "did not see, either at Ereré or in any part of the Amazonas, anything that would suggest glaciation."[3] He still clung, however, to the idea that the highland of Brazil to the south had been glaciated.[4]

Unfortunately Hartt has left no further record of his later views upon this subject, but that his views underwent a radical change I know as positively as one can know the opinions of another person. I went with him to Brazil in 1874, was with him in his work there until his death in 1877, and remained yet five years later—in all eight years in that country. Under his direction I did more or less work in the mountains about Rio de Janeiro for the purpose of sifting the evidence of glaciation in that region, and I am glad to say, in justice to the memory and scientific spirit of my former chief and friend, that long before his death he had entirely abandoned the theory of the glaciation of Brazil, whether general or local, and that the subject had ceased to receive further attention, even as a working hypothesis. So much for Hartt's opinions.

[1] Bulletin of the Buffalo Soc. of Natural History, 1874, 201.

[2] On the Valley of the Amazon, by JAMES ORTON, Proc. Am. Assoc. Adv. Sci., 1869, XVIII., 195–9; On the Evidence of a Glacial Epoch at the Equator, by JAMES ORTON, The Annals and Magazine of Natural History, 1871, VIII., 297–305.

The Andes and the Amazon, by JAMES ORTON, N. Y., 1876, 282, 560. The fossils collected by Orton are described in the Amer. Jour. Conchology, IV., 197, and VI., 192. Others are described from similar places in the Quar. Jour. Geol. Soc., XXXV., 76–88, and 763 *et seq.*

[3] Amer. Jour. Sci., 1871, 295.

[4] Ann. Rep. of the Amer. Geographical Soc. of N. Y., for the year 1870-1, 252.

Thomas Belt, the author of The Naturalist in Nicaragua, says in that volume[1] that though no ice marks are visible he has seen "near Pernambuco, and in the Province of Maranham, in Brazil, a great drift deposit that I believe to be of glacial origin."

I have seen and studied the deposits to which Belt refers; my opinion is that while they bear a certain resemblance to glacial drift they are entirely devoid of positive evidence of glacial origin. The method of their formation is explained in another part of this paper.[2]

AGASSIZ'S CHANGE OF VIEWS.

It is appropriate that I here quote from Professor N. S. Shaler, a former pupil of Professor Agassiz:[3]

"There has been a good deal of discussion concerning the former existence of glaciers in the valley of the Amazon. Agassiz, to whom we owe the first suggestion of the value of glaciation as a great geological agent, at one time thought it likely that the valley of this great river had been the seat of a glacier that poured its ice from the Andes nearly down to the sea. This, which was hardly more than a suggestion put forth for the discussion of geological students, was, I believe, practically abandoned by this illustrious naturalist before his death, (In this assertion I have embodied the results of several remarks by my late master on this subject made during the last two years of his life. It is satisfactory to know that the only considerable mistake he made in the matter of glaciation was corrected by his own reflections on the subject. N. S. S.) and has been found to be an essentially mistaken view. The late Professor Hartt, geologist of Brazil, at one time thought some of the debris in the mountain districts near Rio de Janeiro was of glacial origin, but this suggestion has never been submitted to discussion, and can have no weight against the other evidence of a negative kind that goes to show that glaciation, save in higher mountain countries, has never extended into the intertropical regions."

[1] The Naturalist in Nicaragua, by Thomas Belt, F.G.S., 2d ed. London, 1888, 265.

[2] It has been asked how I reconcile Belt's statements regarding glaciation in Nicaragua with my inability to find trustworthy evidence of glaciation at a similar south latitude. I don't try to reconcile them; I am simply dealing with the facts as I know them in Brazil. I have never seen the Nicaraguan deposits, but I can't avoid suspecting that they will turn out like the Brazilian ones, J. Crawford's moraines and "moutonnéd ridges" to the contrary notwithstanding. (Proc. Amer. Assoc. Adv. Sci., XL., 265, and Science, XXII., No. 263, p. 270).

[3] Glaciers, by N. S. Shaler and W. M. Davis, Boston, 1881, 47.

In 1872 Agassiz went through the Straits of Magellan in charge of the natural history work of the Hassler Expedition. On that voyage he touched at Montevideo and at many points south of that place, through the straits, and along the west coast. The letters written by him on this trip suggest very strongly, if they do not conclusively show, that he had at this time already abandoned the idea that Brazil had been glaciated. Speaking of certain boulders seen by him on the Cerro at Montevideo, Mrs. Agassiz observes[1] that "As these were the most northern erratics and glaciated surfaces reported in the southern hemisphere," etc. From this it appears that he no longer regarded the Brazilian boulders as erratics.

After Agassiz had examined the glacial phenomena of the Straits of Magellan and of the southern part of the continent, he sent a report to the Superintendent of the U. S. Coast Survey, dated at Concepcion Bay, June 1, 1872.[2] This article also bears evidence that he no longer regarded Brazil as having been glaciated. In one place he says,[3] "I am prepared to maintain that *the whole southern extremity of the American continent* has been uniformly moulded by a continuous sheet of ice." The italics are mine. In the next paragraph he says, "The first unquestionable *roches moutonnées* I saw were upon the nearest coast opposite Cape Froward." Again he says (p. 271): "The equatorial limit of this ice sheet both in the northern and the southern hemisphere is part of the problem upon which we have thus far fewest facts in our possession. In South America I have now traced the facts *from the southernmost point of the continent uninterruptedly to 37° S. latitude on the Atlantic* as well as the Pacific coast." Again

[1] Louis Agassiz, his Life and Correspondence, Boston, 1886, II., 712. Rep. U. S. Coast and Geodetic Survey for 1872, 215. Nature, 1872, VI., 69. Evidently Burmeister does not regard the boulders cited as glacial, for he uses the expression, "phénomènes de glaciers chez nous, et dont nous n'avons nulle part la preuve." République Argentine, II., 214, also 392, 393. The same blocks are described by Darwin in his Geological Observations, 432. He does not seem to regard them as erratics.

[2] Published in the New York Tribune of June 26, 1872, and reproduced in Nature 1872, VI., 216, 229 and 260.

[3] Nature, 1872, VI., 230.

(p. 272) he speaks of having traced the palpable evidence of glaciation "from Montevideo on the Atlantic to Talcahuano on the Pacific coast." Speaking of evidence at Concepcion Bay he says also (p. 272) "Think of it! A characteristic surface indicating glacial action in latitude 37° S. at the level of the sea!"

These quotations show as plainly as anything short of a positive statement can that Agassiz in 1872 no longer considered as trustworthy what he had formerly regarded as the evidences of glaciation in Brazil. For if he still believed in a glacier under the equator itself, why should he tell us with exclamation points to think of a glacier thirty-seven degrees nearer the pole?

BASIS OF THE THEORY.

I should be glad to leave the matter with these statements of the changes of views on the part of both advocates of the glaciation of Brazil, but persons who have theories based to a greater or less extent on the glaciation of the tropics are very reluctant to believe, in the face of the many positive statements of both Agassiz and Hartt, and of the apparently trustworthy evidence adduced by them, that the first impressions of those excellent observers, both of whom were thoroughly familiar with glacial phenomena in the north, were altogether wrong. It is not possible, neither is it necessary, to take up here the individual cases spoken of by Agassiz and Hartt as evidence of glacial action. Very nearly all the materials referred by them to the drift fall under two principal heads:

First, the so-called erratic boulders, often imbedded in what was considered boulder-clay.

Second, transported, water-worn materials.

ORIGIN OF THE BOULDERS.

The boulders believed to be erratics are not erratics in the sense implied, though they are not always in place. The first and most common are boulders of decomposition, either rounded or subangular, left by the decay of granite or gneiss. Sometimes they are imbedded in residuary, and consequently unstrati-

FIG. 1. Pão d'Assucur or Sugar Loaf, a Granite Peak at the Entrance of the Bay of Rio de Janeiro.

fied clays, formed by the decomposition in place of the surrounding rock. And everyone has heard of the great depth to which rocks are decomposed in Brazil.[1] The true origin of these boulders and the accompanying clays is often more or less obscured by the "creep" of the materials, or, in hilly districts, by land-slides, great or small, that throw the whole mass into a confusion closely resembling that so common in the true glacial boulder-clays. In this connection too much stress can scarely be placed upon the matter of land-slides; they are very common in the hilly portions of Brazil, and, aside from profound striations and faceting, produce phenomena that, on a small scale, resemble glacial till in a very striking manner. The fact that the boulders are of various sizes, sometimes from ten to twenty feet in diameter, and have mingled with them quartz fragments derived from the veins that traverse the crystalline rocks from which they are derived, adds to the resemblance of these materials to certain glacial products. Such boulders, however, are by no means confined to the vicinity of Rio de Janeiro, but are common throughout Brazil wherever there are granites or gneisses. They have been seen by the writer in the Amazon valley (Araguary River) in the interior of Pernambuco,[2] Parahyba do Norte, Alagôas, Sergipe, Bahia, Rio de Janeiro, Minas Geraes, São Paulo, Paraná, and Matto Grosso.

The positions in which such boulders are often found are worthy of note, though one who felt disposed to regard them as transported blocks would probably not consider their positions as inconsistent with the glacial theory of their orgin. They are abundant about the bases of granite hills and mountains where they have been formed by the exfoliation of the great blocks and slabs produced by the secular decay of the hills and mountains. There are hundreds of rude boulders at the southeast base

[1] DARWIN: Geological Observations, 427; LIAIS: Climats, Géologie, etc., 2; PISSIS: Men. Hist. Inst. de France, X., 538; DERBY: Amer. Jour. Sci., 3d Ser., XXVII., 138; MILLS: Amer. Geologist, III., 351.

[2] In the American Naturalist, 1884, XVIII., 1189, I have given a sketch of some boulders found in the state of Pernambuco; see also p. 1187 of that vol.

Fig. 2. Boulders of Decomposition, Island of Paquetá, in the Bay of Rio de Janeiro.

of the Sugar Loaf at the entrance to the harbor of Rio, at the east base of the Corcovado, and about every such mountain in the vicinity of Rio de Janeiro. They[1] rest on the summits and margins of the high, sharp mountain peaks; on the top of the Sugar Loaf at the entrance of the Rio harbor, for example, there are several such boulders, one of which is thirty feet in diameter; the top of the Gavea, the flat-topped mountain southwest of Rio, has hundreds of boulders on its summits. Agassiz mentions such boulders on the edge of rock basins (Journey, 493). He "was at a loss how to explain how loose masses of rock, descending from the heights above should be caught in the edges of these basins, instead of rolling to the bottom." The fact is that the blocks referred to originated, not in the heights above, but just where they now lie, as is shown beyond question by occasional quartz veins passing from the boulders into the rocks upon which they rest.[2]

In some of the shallow parts of the Bay of Rio de Janeiro what were once small islands have had the residuary soils removed and great nests of such boulders project from the water.[3] On the island of Paquetá in the bay are some beautiful examples of such boulders lying in the water's edge. I am fortunately able to give an illustration showing the Paquetá boulders which may be taken as a type of those found in and about the Bay of Rio de Janeiro.

The second method by which these boulders have been

[1] Sometimes boulders accumulate on one side of a hill or peak and not on the opposite side. This is well illustrated in the case of the Sugar Loaf. On the side facing the ocean there are thousands of boulders, many of them of enormous size, while on the opposite side where there is less surf there are but few. The reason for this difference is that there is a large dike-like ledge of hard rock exposed on the seaward side of the peak. This ledge does not appear on the opposite side where the mass is softer and weathers away evenly without leaving good boulder-forming fragments about the base. The ledge referred to is shown in the accompanying illustration.

[2] In SHALER and DAVIS' Glaciers, plate XXII., is given an example of boulders of decomposition in Central India. Exactly similar cases are common in the granitic and gneissic areas of Brazil.

[3] See also BURMEISTER'S Reise nach Brasilien, Berlin, 1852, 111, 112.

formed is quite similar to the first, but instead of being cores of granite or gneiss, they have been derived by the same process of exfoliation and decomposition from the angular blocks into which the dikes of diorite, diabase, or other dark colored rocks break up. Their color marks them as quite different from the surrounding granites, and the dikes themselves are almost invariably concealed. Moreover, these dikes not infrequently contain inclusions of still different rocks and we thus occasionally have boulders of various kinds of rocks mingled together. The residuary clays derived from the decomposition of these dikes are somewhat different in color from those yielded by the granites, so that when "creep" or land-slides add their confusion to the original relations of the rocks, the resemblance to true glacial boulder-clays is pretty strong. The chance of discovering the source of these boulders is further decreased by the depth to which the mass of the rock has decayed, and by the impenetrable jungles that cover the whole country and so effectually limit the range of one's observation. Dikes such as these last mentioned are not uncommon in the mountains of Rio de Janeiro. Indeed what have generally been regarded as the very best evidences of Brazilian glaciation,[1] some of the boulders near the English hotel in Tijuca, fall under this head, though some of them are of gneiss. The fact is that the great mountain masses about Rio are of granite or gneiss, while some of the boulders come from dikes or other dark-colored rock high on their sides, dikes which were not visited by Agassiz or Hartt.[2] There is a good example of a dike breaking up in boulders at the gap through which the road passes from the Jardim Botanico to the Gavea near the City of Rio. At this place the ground is covered to a

[1] A Journey to Brazil, 86 *et seq.*; AGASSIZ: Geological Sketches, Boston, 1885, II., 155 *et seq.* HARTT'S Geol. and Phys. Geog. of Brazil, 24–30.

[2] Darwin mentions boulders and dikes seen at Rio de Janeiro, (Geological Observations, pt. II., ch. XIII., 425; also Trans. Geol. Soc. London, 2d Series, 1842, VI., 427, note). Professor O. A. Derby sent Rosenbusch specimens of diabase from twelve dikes in the neighborhood of Rio de Janeiro, varying from twenty centimetres to several metres in thickness. See Dr. E. O. HOVEY'S descriptions of these rocks in Tschermak's Min. u. Petrog. Mittheilungen, 1893, XIII., 211–218.

depth of fifteen feet or more with clays through which are mingled boulders of diorite and granite and fragments of quartz. Further east, at a lower level, some of the clays have been washed over and contain subangular fragments of quartz, some of them two feet in diameter, many of which are somewhat water-worn. It is perhaps worth mentioning that these water-worn quartz fragments imbedded in clays were regarded by Hartt as the best evidence of glaciation. They were finally eliminated as such evidence near the end of a rainy season by my finding a landslide filling up a small ravine in which the bed of the stream had been strewn with similar quartz fragments, and the whole buried beneath a slide of crumpled clays. A highly instructive lesson can be had on the subject of boulders and clays, their origin and relations to the so-called drift of Brazil from Professor Derby's paper on nephelene rocks in Brazil.[1] Anyone reading that article can readily fancy how Professor Agassiz, in a flying trip across São Paulo and Minas, would have interpreted these clays and boulders of different kinds and different colors.

In regard to the so-called erratics I should mention also the opinion of another observer and writer upon Brazilian geology. Emmanuel Liais, formerly director of the Imperial Observatory at Rio de Janeiro, is very positive that there are no evidences whatever of glaciation in Brazil. Of the boulders supposed to be erratics, he says :[2]

"These boulders though numerous are always in the immediate neighborhood of the veins from which they are derived. . . . . Though presenting sometimes the appearance of erratics by their abundance and rectilinear arrangement, they are not transported boulders, and have nothing in common with erratic phenomena. . . . . I have not been able to find any signs of the existence of a boulder that can be regarded as erratic and coming from a region distant from the one where it is found. In the vicinity of these isolated boulders one always finds dikes, veins or simply masses or boulders of the same material intercalated with the terrain in place."

He speaks of the occurrence of dikes of diorite from which many of the boulders cited by Agassiz have been derived. More

[1] Quar. Jour. Geol. Soc., 1887, XLIII., 457–473.

[2] Climats, Géologie, etc., du Brésil, Paris, 1872, 18.

than a score of statements of a similar nature may be cited from Liais' book.

Count de la Hure has also pointed out how diorite breaks up into boulders, and cites in evidence some of the very cuts on the Pedro II. Railway which Agassiz and Hartt refer to the drift. Saldanha da Gama in speaking of the exfoliation and decomposition of granite rocks described by Count de la Hure and Capanema says :[1]

"This and many other facts gathered by the Brazilian naturalist in his observations on diorite and other rocks of that class led the eminent Swiss geologist to point out that the study of the drift in Brazil will not be well understood so long as one hasn't a thorough knowledge of the decomposition of the rocks."

He also refers to the fact that these phenomena may be observed in several of the Brazilian provinces.

The two kinds of boulders above mentioned are common in the regions of crystalline rocks ; a third kind is found in those parts of eastern Brazil that are covered, or were formerly covered, by Tertiary sediments, namely in the State of Bahia, and thence northward to the Amazon valley. These Tertiary deposits contain beds of sandstone that are sometimes locally changed upon exposure to the hardest kind of quartzite. Most of the associated beds are friable and easily eroded, so that when the surrounding strata have been removed there are left behind a few blocks of quartzite, varying in size from a foot to four feet in diameter. These boulders are so unlike the rocks from which they have been derived and by which they are surrounded, that unless one has given special attention to the study of Tertiary sediments in that region he is liable to be much puzzled and even misled by them.[2]

ORIGIN OF THE WATER-WORN MATERIALS.

The second class of evidences by which Agassiz and Hartt were misled consisted of transported, water-worn materials.

[1] Revista do Instituto Historico do Brazil, 1866, XXIX., 421 *et seq.*

[2] See BRANNER'S Cretaceous and Tertiary Geology of the Sergipe-Alagôas Basin of Brazil. Trans. Amer. Phil. Soc., XVI., 1889, 419–421.

These materials are made up of boulders, cobbles, and gravels, sometimes assorted and sometimes having sand and clay mixed with them, and are spread far and wide, though irregularly, over all the Tertiary and Cretaceous area bordering the ocean, and extend for a long distance into the interior, and far beyond the borders of the Tertiary deposits. They were regarded by the writers in question as analogous to the water-worn materials so common in the northern drift. Had these materials been of glacial origin it is not unreasonable to expect that striated pebbles would have been found among them occasionally, but, as a matter of fact, no such marks have ever been found, though I have made the most diligent search for them. That the striæ have been obliterated by weathering agencies is out of the question, because the preservation of the water-worn and pitted faces of the pebbles shows plainly enough that striated faces would have been preserved equally well had they ever existed. The origin of these water-worn materials has already been explained elsewhere, and from that article the following quotation is made :[1]

"This formation is spread over the hills and valleys of the Sergipe-Alagôas basin and over the adjacent country in the form of a thin coating of cobblestones, pebbles and sand, sometimes loose and sometimes cemented into a pudding-stone as much as ten feet in thickness, and, when exposed, stained black by manganese. It caps the summit of the tertiary plateaux or their outliers, and it is frequently strewn along down the sides of hills and accumulated in the valleys. It is not confined to the geographic limits of the Cretaceous or Tertiary, but is found further inland and far beyond the present limits of these formations. It is everywhere more or less irregular in thickness, and nowhere can it be said to be universal or continuous. The writer has seen this material throughout Sergipe and Alagôas, in Parahyba, and as far inland as the head waters of the Rio Ipanema in the interior of the province of Pernambuco, where there is no remnant of stratified Tertiary beds. Between the lower Rio São Francisco and the frontier of the province of Alagôas, and indeed in many parts of the province of Pernambuco, this water-worn material is found mingled in bogs with the remains of extinct, gigantic mammals.

One of the marked characteristics of this post-tertiary formation is that it is much coarser inland, and grows finer as the coast is approached. The

[1] Trans. Amer. Phil. Soc., 1889, XVI., 421.

explanation of this water-worn material seems to be that the Tertiary period was closed by a depression along the present coast, which carried the beach line far inland, or that it was already there. Then followed a gradual emergence,[1] during which the whole area now covered by this widely distributed water-worn material was passed gradually through the condition of a beach, upon which the then loose, angular, surface rocks of the country were rounded and worn into the boulders, cobbles and pebbles which we now find scattered over this region. While the surf was beating upon and wearing the hard crystalline and metamorphic rocks of the interior it was unable to produce any very marked effect upon the topography of the country, but when, in the course of the land's emergence, the soft, sandy and clayey beds of the Tertiary were brought up within its reach, the work of land sculpture it was able to do was enormously increased. During the emergence of these Tertiary beds they were deeply eroded, and the mud which originally made part of them was washed seaward, and the coarser materials were concentrated upon the slowly receding beach. In some places these accumulations assume unusual proportions, as if they had been brought together by the gradual beating of waves along a beach, or had been reconcentrated by later streams."

GLACIAL TOPOGRAPHY.

Agassiz considered that the undulating outlines of the topography about Rio de Janeiro were attributable to glacial action,[2] though he recognizes the fact that nothing of glaciation was to be learned from their appearance.[3] A careful study of those features, made with this suggestion in mind, shows that the rounded hillsides have no uniformity in their arrangement, that is, what would be *stoss* sides, judging from the topographic forms, face now in one direction, and now in another, and that the outlines are simply those produced by ordinary decomposition and erosion, though much influenced by structural features. Hartt's opinion, as originally expressed in his book (p. 33), was that the forms of the hills were "due primarily to subaërial denudation."

THE ABSENCE OF STRIÆ.

A bit of negative evidence of great importance against the glacial hypothesis is the fact that nowhere has there been found

[1] See also Pissis in Comptes Rendus de l' Acad. des Sci., 1842, XIV., 1046.

[2] Geological Sketches, II., 157. Bul. de la Soc. Géol. de France, 1867–8, XXV., 687.

[3] Journey, pp. 69–70.

a single scratch either upon the rocks in place or upon a boulder, cobble, or pebble, that could, by any legitimate stretch of the imagination, be attributed to glacial action. And it is but just to recall the fact that both Agassiz and Hartt recognized this as the one piece of evidence, above all others, lacking for their Brazilian glacial theory. How diligently Agassiz searched for such evidence one can judge from the story of his journey as told by Mrs. Agassiz and himself, and I know that Hartt left no stone unturned and no locality unexplored that he thought might afford him the long-sought striæ. They both explained the absence of such marks by supposing that they had been obliterated by the decomposition of the rocks, and Agassiz believed that in the Amazon region there were no rock surfaces exposed.[1] But it cannot be considered credible that glacial striæ should have been preserved in Asia, Africa and Australia since Carboniferous times,[2] but entirely obliterated in Brazil, both from the bed rocks and from the conglomerates deposited in post-tertiary times, or as has already been mentioned, that the pitted and water-worn faces should have been preserved in these materials while the ice marks should have been obliterated.

James E. Mills, a professional geologist and a former pupil of Agassiz at Harvard, spent nearly two years in Brazil in the states of Rio Grande do Sul, Rio de Janeiro, and Minas Geraes. He expresses his views of the subject of glaciation in that country as follows:[3] "In those portions of Brazil which came within my field of observation there is no glacial drift, and there are no glaciated rock surfaces or glacial topography or other signs of the existence of glaciers."

Agassiz points out the weakness of his own theory regarding Brazilian glaciation very nicely in his letter to Professor Pierce,

[1] Journey, 426. There are plenty of rock surfaces in the Casaquiari region, on the Araguary, the Tocantins, the Tapajos and in hundreds of other places away from the immediate alluvial plain of the Amazon.

[2] Geological Magazine, 1886, 492–495. For the literature of the subject see C. D. White in Amer. Geologist, May, 1889, 299–330.

[3] American Geologist, III., 361.

of Harvard, by saying: "But I have not yet seen a trace of glacial action proper, if polished surfaces and scratches and furrows are especially to be considered as such."[1]

BIOLOGICAL EVIDENCE.

Thus far I have confined myself to a statement of the facts that relate directly to glaciation. Aside from these a matter of the utmost importance is the continuity of life from Tertiary times down to the present, especially in the tropical and subtropical parts of the earth. If glaciation had been cosmic, as suggested by Agassiz—if it had taken place under the very equator—then the reasoning of biologists regarding the origin and distribution of the present life of the globe is about all at fault. A reviewer of Hartt's Geology of Brazil long ago called attention to the fact that "the grand objection to the theory of the former existence of a continental glacier in tropical America, is the unbroken continuity of tropical life since the close of the Tertiary period."[2] Mr. Wallace, in an earlier review, had already called attention to the same point,[3] while still another lays stress upon the important fact that the plants found in the Amazonian silts, supposed by Agassiz to be of glacial origin, are the remains of tropical plants, and are not therefore comparable with the Alpine plants growing beside existing glaciers in mountainous regions.[4]

THE OPINIONS OF OBSERVERS.

The following are some of the opinions of geologists regarding the phenomena regarded by Agassiz and Hartt as glacial. These authors are quoted, not simply for the purpose of bringing the weight of authority to bear on the subject, but because they have all seen much of the geology of Brazil and are competent to have opinions worthy of consideration. Darwin, who visited Brazil in 1832 and saw something of these

[1] Journey in Brazil, 88.

[2] American Naturalist, 1871, V., 36.

[3] Nature, 1870, II., 511.

[4] The Geological Magazine, 1868, V., 458.

phenomena, stated that no true glacial boulders had been seen in the inter-tropical regions.[1] The English botanist, George Gardner, gives the correct explanation of the formation of the soils about Rio.[2] Burmeister, who traveled extensively in Brazil, is of the opinion that the facts appealed to by Agassiz in support of his glacial hypothesis for Brazil are to be explained otherwise.[3] Liais' adverse opinion has already been cited. Dr. Guilherme S. de Capanema, a Brazilian geologist, thoroughly disbelieves in the theory of Brazilian glaciation.[4] Professor James Orton's papers in which he controverts the glacial hypothesis in so far as it relates to the Amazon valley have been cited, while Hartt himself recognized the mistake of Agassiz in that region.[5] Mr. James E. Mills saw some of the best examples of the supposed glaciation at Rio de Janeiro and spent more than a year in the highlands of Brazil; his opinion regarding what he saw has already been quoted. Professor Derby in speaking of the possibility of glaciaation omits all reference to the phenomena upon which Agassiz and Hartt placed so much stress, namely, those in the mountains about Rio, though to my knowledge, he is perfectly familiar with those phenomena.[6]

[1] Trans. Geol. Soc. London, 1842, 2nd Ser. VI., 427.

[2] Jour. Roy. Hort. Soc., 1846, p. 191.

[3] Description Physique de la République Argentine par Dr. H. Burmeister, Paris, 1876, II., 393.

[4] Decomposição dos penedos do Brazil, Rio de Janeiro, 1866; Revista do Instituto Historico do Brazil, 1866, XXIX., 421.

[5] Am. Jour. Sci., 1871, 295.

[6] In the following references more or less doubt is expressed regarding the glaciation of Brazil:

The Highlands of Brazil, by RICHARD F. BURTON, London, 1869, I., 39, II., 218. The Amazon and Madeira Rivers, by FRANZ KELLER, New York, 1874, 47. Fifteen Thousand Miles on the Amazon, by BROWN and LIDSTONE, London, 1878, 42. Brazil, the Amazon and the Coast, by HERBERT H. SMITH, New York, 1879, 634. Glaciers, by SHALER and DAVIS, Boston, 1881, 47. A Geographia Physica do Brazil por J. E. WAPPEUS, Rio de Janeiro, 1884, 55. Pre-historic America, by the MARQUIS DE NADAILLAC, edited by W. H. DALL, London, 1885, 18, foot note. Report on Coffee Culture, by C. F. VAN DELDEN LARENE, London, 1885, 24. Le Pays des Amazones par F. J. de SANTA-ANA NERY, Paris, 1885, 36. A Year in Brazil, by H. C. DENT,

I may sum up my own views with the statement that I did not see, during eight years of travel and geological observations that extended from the Amazon valley and the coast through the highlands of Brazil and to the head waters of the Paraguay and the Tapajos, a single phenomenon in the way of boulders, gravels, clays, soils, surfaces or topography, that could be attributed to glaciation. A glacial origin for certain gravels has probably been suggested by Derby,[1] because their origin is somewhat obscure, but I am of the opinion that they admit of the same explanation as the high river gravels of the south-western United States, and that glaciation had nothing whatever to do with them.[2]

JOHN C. BRANNER.

London, 1886, 424. Three Thousand Miles through Brazil, by J. W. Wells, London, 1886, II, 373–4. Sparks from a Geologist's Hammer, by ALEXANDER WINCHELL, Chicago, 1887, 180. Notes of a Naturalist in South America, by JOHN BELL, London, 1887, 313–318 and 342. Darwinism, by ALFRED R. WALLACE, London, 1889, 370.

[1] WAPPEUS' Geographia Physica do Brazil, p. 55.

[2] It may have some value as corroborating an opinion formed before studying the geology of the Southern United States, that all the phenomena brought forward in support of the glaciation of Brazil are repeated in the Southern States, far south of what geologists readily recognize as the utmost limits of glacial ice. In Arkansas for example, boulders occur near Little Rock, of such shape, character, and distribution as to strongly suggest a glacial boulder train, if the glaciation of the region were admissible, or another explanation were not evidently the correct one. For an illustration of such boulders see Annual Rep. Geol. Survey of Arkansas for 1890, II., 25.

CAUSES OF MAGMATIC DIFFERENTIATION.

In petrographical literature in recent years attention has repeatedly been drawn to the fact, that igneous rocks, which are closely connected geographically and in age, are also chemically related to one another, showing a certain "consanguinity"—to use Iddings'[1] very fitting expression—a relationship which makes them form a distinct "petrographical province" (Judd) when compared with igneous rocks of other parts of the world. The cause of this relationship has been sought in the supposition, that all the different rocks of the "petrographical province" come from the differentiation of one common magma, originally homogeneous.

As to the manner in which the differentiation took place, opinions are divided. We may suppose that it took place during the consolidation of the magma; in this way, a part of the minerals crystallized out, then were mechanically accumulated and finally reliquified. The differentiation of the original magma into partial magmas could take place in this way, but, as far as I can see, only on a small scale. A silicate magma during its period of crystallization is certainly too viscous to permit of any considerable diffusion. For example, in the reproduction of rocks after the method of Fouqué and Lévy, in which process a glass is first made having the desired composition, this glass may be completely devitrified (fused), while it remains so viscous that pieces of it neither change form nor adhere to one another.

Another theory, namely, that the differentiation has taken place in the magma while quite fluid, possesses greater probability and therefore more adherents. But concerning the details of the method opinions differ. While certain petrographers apply the

[1] "Origin of Igneous Rocks." Bull. Phil. Soc. of Washington, 12. 89–214. (1892). This paper contains an extensive bibliography of this subject, to which the reader is referred.

laws of dilute solutions to explain the differentiation of the molten silicate magmas, others look upon the separation of the original magma into partial magmas as evidence of the incapacity of the chemical compounds, constituting the original magma, to dissolve one another completely at all states of temperature and pressure. This latter theory is not as yet very much developed, but has been considered by Durocher and Rosenbusch, whereas the first theory, which consists essentially in the application of what Teall has termed "Soret's principle," has been used by several authors, in greatest detail by Vogt.

The principle known in petrographical literature as "Soret's principle" can be correctly formulated thus: "If in the same dilute solution, the temperature is different in different places, the concentration varies also and in such a manner, that, when equilibrium is established in every point, it is universally proportional to the absolute temperature"—for, the osmotic pressure is proportional to the absolute temperature, and if the pressure is augmented in one place, part of the molecules must be driven over to the place with less osmotic pressure, in order to maintain the equilibrium. Here, as in the other applications of the laws of gases to solutions, it must be remembered that these laws apply rigidly only to very dilute solutions; concerning the behavior of concentrated solutions we know very little, and especially with reference to "Soret's principle." Further, if two or more substances are contained in the solution a difference of temperature could not change the *relative* concentration any more than it could change the composition of a gas-mixture.[1] The only thing that is altered is the proportion between the solvent and the substance dissolved.

Consequently such definitions of "Soret's principle" as "The compound or compounds with which the solution is nearly saturated tend to accumulate in the colder parts,"[2] and "The most

[1] In very concentrated solutions it might happen that the osmotic pressure is a different function of the temperature for the different substances in solution, and then the relative concentration would be changed.

[2] TEALL: "British Petrography," 394. (London, 1888). ZIRKEL: "Lehrbuch der Petrographie," Vol. I., 779. (Leipzig, 1893).

difficultly soluble compounds diffuse towards the plane of cooling"[1] are misconceptions. It is the proportion between the solvent and the dissolved substance which is changed and this is all—so far as we know at present. Consequently, in order that one may use "Soret's principle" for the purposes of theoretical petrography it is quite necessary to have the question settled: what is "the solvent" and what "the thing dissolved?"

Vogt[2] avoids this difficulty in the following way. He says: "Owing to chemical action certain 'liquid-molecules' are individualized, which are preliminarily kept dissolved in the resting magma, and which only by a subsequent lowering of temperature, or pressure, are separated in the solid condition. The minerals which crystallize first at every stage may consequently be considered originally 'dissolved' in the remaining 'mother-liquor.'" Here we find at first the supposition, that certain compounds are "individualized"[3] in preference to others, and consequently the latter as not "individualized" form a sort of chaos. But this remainder must certainly consist also of chemical compounds. The author has perhaps thought that they should be dissociated, but it must be remembered that the free ions cannot diffuse independently of one another.

In the latter part of the quotation it is stated, that the substance which crystallizes out first when temperature sinks is to be considered as dissolved in the solvent, which crystallizes at a still lower temperature. But, in general, it is the solvent which crystallizes out first when the temperature falls, and this crystallization goes on until the "eutectic proportion" (Guthrie) is reached, when both the substance dissolved and the solvent crystallize simultaneously until the whole is solidified. If Vogt's reasoning is correct, the more a dilute solution of nitre is diluted with water, so much the more should the water be regarded as the substance dissolved.

[1] "Die am schwersten löslichen Verbindungen diffundiren nach der Abkühlungsfläche hin." BRÖGGER: Zeitschr. f. Krystallographie 16, 85. (1890).

[2] Geologiska Föreningens Förhandlingar 13. 526. (Stockholm, 1891).

[3] Or "constituted" in the German edition, Zeitschr. f. prakt. Geol., 1893, 273.

Thus I have tried to show, that "Soret's principle" cannot be applied to magmas, and consequently, if magmatic differentiation were a process of molecular diffusion it could not be explained. And it seems to me to be going too far to apply the laws of dilute solutions to magmas before having attempted to consider them simply as mixtures of liquids.

As an illustration of the conduct of two liquids when mixed, let us take aniline and water. If they are mixed at ordinary temperature, when equilibrium is established two layers are formed, one containing 1 per cent. of aniline and 99 water, the other 98 aniline and 2 water.[1] But if they are mixed at 100° the two layers formed will contain 4 aniline and 96 water, and 91 aniline and 9 water; at 150° the proportions are 14 aniline and 86 water, and 76 aniline and 24 water; at 160° they are 25 aniline, 75 water, and 68 aniline, 32 water, and at 166° the two layers should have the same composition, being consequently identical. Therefore, *above* 166° aniline and water mix in all proportions, but *below* this temperature the reciprocal dissolving capacity is limited and generally a separation into two layers takes place, the composition of which is a function of the temperature.

This seems to be common for all liquid-mixtures where no chemical action takes place. For all such mixtures there exists a temperature, above which they mix in all proportions. It is true that this temperature is known only for a few combinations of liquids, but it must be regarded as certain that it exists, and if not below then at the critical temperature, because here the capacity of mixing in all proportions is a general property of the gases.

On the other hand, there are certain fluids, which at ordinary temperature dissolve one another without limit, and for these the temperature below which the dissolving capacity is limited is yet to be determined, but in some cases this may not be reached before the transition into the solid form takes place. For us the principal question now is, can we assume that all the chemical

[1] The numbers given are obtained by interpolation in the curve of Alexejew in WIEDEMANN'S Annalen 28, table 3. (1886).

compounds forming the original rock magma are completely soluble in one another? I think not.

We are told by Vogt[1] that silicates can be melted together in all proportions. This may be true, but it does not prove that this mixture would not separate into layers of different composition, or at least become heterogeneous, if it were kept molten for a sufficient time. The viscosity of molten glasses is very great and consequently the separation must take time. Still evidences of such separation—or *liquation* as we may call it, following Durocher—in the manufacture of glass are not wanting. It is well known to be very difficult to produce large pieces of homogeneous glass, for example for optical purposes. According to Wagner's Handbuch der chemischen Technologie[2] this comes from the fact, "either that the individual compounds formed during the melting process have not dissolved one another or that they have separated from the mixture by a lowering of the temperature"; and further, "One will seldom find large pieces of glass, which are completely free from this fault."[3] But it is not necessary to leave the field of geology in order to decide the question whether magmatic differentiation is a diffusion, or a liquation, process. Let us select some examples of differentiation, and examine them in the light of both theories. I have chosen two, one on a small scale, the basic inclusions, and one on a large scale, the great petrographical province of Iceland.

By diffusion, according to "Soret's principle," the basic inclusions could never be thought to have been formed in situ or approximately so—for, between them and the surrounding magma there would be no difference in temperature, or at least no difference sufficient to alter the osmotic pressure, which is proportional to the absolute temperature, or enough to produce

[1] Zeitschr. f. prakt. Geol., 1893, 272.

[2] 13th edition, 720. (Leipzig, 1889).

[3] "Entweder die einzelnen beim Schmelzprocesse entstandenen Verbindungen sich gegenseitig nicht aufgelöst, oder bei einem Nachlassen der Temperatur aus einem Gemenge sich abgeschieden haben"; and further, "Man wird selten grössere Stücke von Glas finden, welche von diesem Fehler vollkommen frei wären."

so radical a change in chemical composition. These inclusions must, by this theory, be considered to be fragments of older rocks, formed in this way. Still basic inclusions may be supposed to have been formed by mechanical agglomeration, and no doubt this has often been the case. But, in opposition to both these theories, it is in many cases evident that the inclusions were *soft*, and then the simplest view is that they were drops, or portions, of a partial magma, which at the temperature, existing immediately before crystallization, could no longer be held in solution by the principal magma, but separated out,

The great petrographical province of Iceland is characterized principally by enormous eruptions of plagioclase-basalts and exceedingly subordinate eruptions of rhyolites, which, however, are very numerous. No other eruptive rocks are known from Iceland up to this time.[1] If we considered the differentiation of the primary magma, which here was very basic, as a diffusion-phenomenon, according to "Soret's principle," it would be incomprehensible why the differentiation never stopped with the production of an intermediate magma, and, moreover, this theory would demand that every little rhyolite-magma previous to the eruptions would have been surrounded by a broad zone, showing all transitions to the basaltic magma. In both cases these intermediate magmas should have been erupted at some time, but, as already mentioned, we know a hundred eruptions of rhyolite but not a single one of andesitic rocks. It therefore seems more probable that these intermediate magmas never existed in the petrographical province of Iceland, but that the acid partial magmas were separated out directly from the basic original magma, which by lowering temperature lost its homogeneity. The conditions of temperature and pressure being different in different places these acid partial magmas also became somewhat different, but may all be classified as soda-rhyolites. The chemical compounds, which constitute the silicate magmas—and which are not necessarily identical with the rock-forming

[1] Refer to H. BÄCKSTRÖM: "Beiträge zur Kenntniss der isländischen Liparite" in Geol. Fören. Förh. 13, 667. (Stockholm, 1891).

minerals—are naturally more than two, and therefore the liquation must become very complicated, being not only a function of temperature but also dependent on the original proportions. Therefore, in other places, where the original magma had another composition, relatively stable andesitic magmas might be formed, but this was evidently not the case in Iceland.

Liquation is no doubt also a function of the pressure, but experimental data are wanting. Still it may be considered as probable that, if liquation would augment the volume of the magma, then pressure would act the same as increase in temperature, and inversely. The first is most frequently the case with liquid-mixtures.

The purpose of this communication is to give to liquation and not to diffusion its place as the working hypothesis, upon which the theory of differentiation is to be constructed. How far this theory may differ from the approximation to it, given by Rosenbusch in his "Kern"-theory, the future will show.

In conclusion, I wish to express my best thanks to my friend and colleague Dr. S. Arrhenius for much valuable information furnished me in numerous discussions on this and other subjects which lie on the border between petrology and physical chemistry.

HELGE BÄCKSTRÖM.

THE GEOLOGICAL STRUCTURE OF THE HOUSATONIC VALLEY LYING EAST OF MOUNT WASHINGTON.[1]

(With Plates V, VI, VII.)

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CONTENTS.

In a former paper[2] I have discussed the geological structure of Mount Washington and shown that in that mass we have to deal with a conformable series of beds embracing four distinct lithological members. These members are: (1) a lower dolomitic limestone—the Canaan Dolomite; (2) a lower schist member containing usually abundant garnets and frequently also staurolite—the Riga Schist; (3) a calcareous member, in the valley a marble but on the summit plain of the mountain and along its base very micaceous and graphitic—the Egremont Limestone; and (4) a schist member very feldspathic and

[1] Part of a report of work done as Assistant Geologist in the Archean Division of the U. S. Geological Survey, under the direction of Professor Raphael Pumpelly.

[2] On the Geological Structure of the Mount Washington Mass in the Taconic Range. Journal of Geology, Vol. I., p. 717.

usually either chloritic or sericitic, but always free from garnets and staurolite—the Everett Schist.

The area studied.—To the eastward of Mt. Washington, at a distance of five or six miles, flows the Housatonic river, its general course being like the crest-line of the mountain, nearly south. To the northeastward of the mountain the intervening area is a nearly level plain in which are extensive outcrops of the Egremont Limestone, sometimes with thin intercalated micaceous or quartzitic layers. This limestone belt extends almost to the river at Great Barrington and Sheffield Plain. South of the village of Sheffield, however, the level expanse of the plain is broken by the occurrence along its eastern margin of low, sharp ridges trending northeasterly to northwesterly, and increasing in number as well as in height and breadth in going south. The area covered by these ridges begins at Sheffield where two narrow ridges are separated by only a few hundred feet, and broadens steadily in going southward, thus narrowing the belt of limestone on its western border, and finally cutting it off near the village of Salisbury by making connection with the southeastern base of Mt. Washington. (Cf. Plate III. of Mt. Washington paper). Corresponding with the increase in breadth which characterizes the area in its southern portion, there is a marked increase both in the height and the width of the individual ridges. East of the Twin Lakes in Salisbury is Tom's Hill, which rises to a height of over 1,200 feet, while further south, to the east of the village of Salisbury, is Barack M'Teth (1,300 feet), and Watawanchu Mountain (1,300 feet), and farther east in about the latitude of Watawanchu Mountain is Mt. Prospect[1] (1,460). This tongue of alternating schist ridges so sharply outlined, presents so much of unity in topographical and geological features as to be eminently suited to separate treatment. As the ridges are composed of the Riga and Everett Schists, the area is closely connected geologically with Mt. Washington. This paper is devoted to the consideration of

[1] To be distinguished from one of the northwest peaks of Mt. Washington which bears the same name.

the structure within this tongue-like area, which includes between twenty and twenty-five square miles. The field work was mainly done in 1888, though the southern portion of the area was revisited in 1891, when the writer was assisted by Mr. Louis Kahlenberg, and again in 1892 when he was assisted by Mr. H. J. Harris. The work has been in charge of Professor Pumpelly, then the head of the Archean Division of the U. S. Geological Survey.

Views of Percival and Dana regarding the area.—Though the map accompanying Percival's report does not indicate the schist areas within the area which is under consideration, he several times mentions them in the text. One is surprised to find how accurate were his observations and how correct his views regarding the area, notwithstanding the limited facilities and unsatisfactory condition of his survey. The following extracts from his report[1] contain the more important statements which he made having reference to this area.

"It (the limestone) is accompanied throughout with Mica Slate sometimes forming thin interposed beds, and at other times extensive ranges. The Mica Slate, in the vicinity of the limestone, particularly when interposed in thin layers in the beds of the latter, is very generally dark and plumbaginous, but occasionally light gray, as in the more extended ranges. These latter usually occupy high narrow abrupt ridges, sometimes quite isolated, and at other times in longer ranges, generally with an irregular outline." (Pp. 126–127).

"A coarse dark Mica Slate, veined or knotted with quartz, and often abounding in staurotides and garnets, occurs especially in the north part of the ridge bounding, on the west, the valley south of Lime Rock village, ..." (P. 127).

"The general surface of the valley, in the north part of Salisbury, in Canaan, and in the adjoining part of Massachusetts, is low and level, but traversed by ridges of Mica Slate, often high and abrupt, either isolated, or in long continuous ranges, the latter generally presenting a distinctly curved outline." (P. 129).

"Between these two branches[2] extends a series of Mica Slate ridges, continued north from the ridge bounding the valley at Weed's Quarry (Kl.) on

[1] Report on the Geology of Connecticut, by JAMES G. PERCIVAL, New Haven, 1842, pp. 124–130.

[2] Of the Housatonic Valley.

the west, in a very undulating course, and marked by several transverse depressions, to a high isolated summit,[1] adjoining the north line of the east of the North Ponds[2] (Salisbury)." (P. 129).

In a paper read before the American Association in 1873[3] Professor J. D. Dana quotes Percival as stating that the mica schist in which he found garnets in the township of Salisbury, is below the "Stockbridge or Canaan Limestone," but giving it as his own view that the schist is the overlying rock. This observation of Percival has considerable interest, for though the "Stockbridge or Canaan Limestone" has been shown to consist of two members, one of which is below and the other above the Staurolite-bearing rock, it is probable that Percival discovered a locality at which the Riga Schist comes out from below the Egremont Limestone.

On the map accompanying Professor Dana's paper entitled Taconic Rocks and Stratigraphy,[4] a number of schist areas are represented within the area here treated, which he correctly described to be, in some cases at least, "isolated within the limestone area,—as isolated as islands in a sea."[5] He mentions eleven of them in Salisbury and eight in the part of Sheffield township just north. He believed that there is but one schist horizon, which overlies the limestone, and described three localities, nearly or quite within the area studied, to sustain his views. These are, (1) the hill three miles north of Gallows Hill (locality 4, l. c., p. 213) where the schist "overlies the limestone"; (2) Turnip Rock (locality 5, l. c., p. 213) where schist overlies limestone in a shallow synclinal; and (3) Tom's Hill in Salisbury, which is described as a very flat trough of schist toward the north, but developing farther south into an overturned synclinal with its axis dipping east (l. c., p. 214). The observations made by

[1] Tom's Hill.

[2] Twin Lakes.

[3] On Staurolite Crystals and Green Mountain Gneisses of the Silurian Age, by J. D. Dana. Proc. A. A. A. S., 22d (Portland) Meeting, 1875, p. B25.

[4] American Journal of Science, Vol. XXIX., June, 1885.

[5] Amer. Jour. Sci., Vol. XXIX., March, 1885, p. 211.

the writer accord with those of Professor Dana in the second instance only, which relates to the upper or Everett schist member. As will be fully shown below, the other mentioned localities have a much more complicated structure than was supposed by Professor Dana.

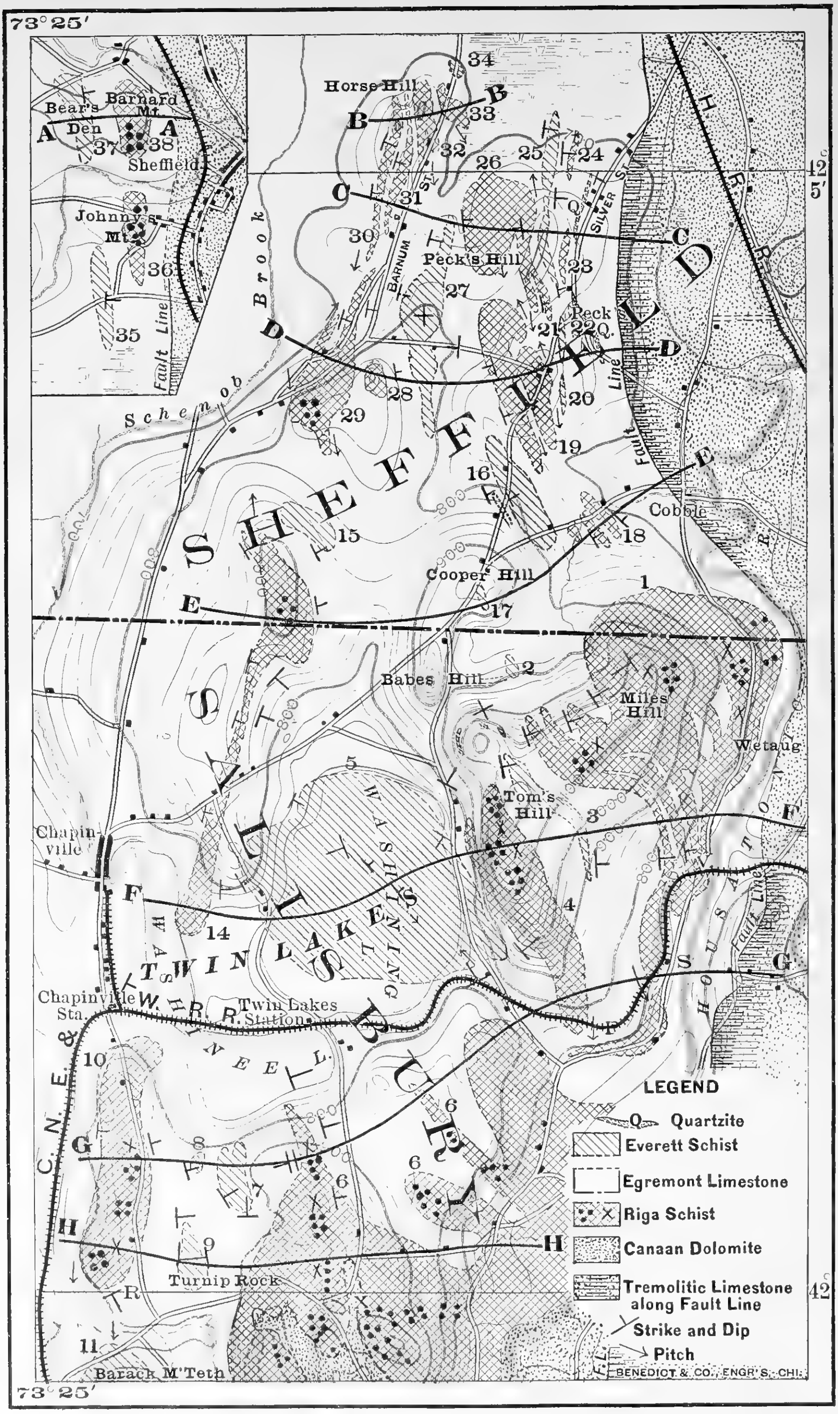
LITHOLOGICAL CHARACTERS OF THE HORIZONS.

As has already been stated, the horizons outcropping within this area all belong to the Mt. Washington series, viz.: The Canaan Dolomite, the Riga Schist, the Egremont Limestone, and the Everett Schist. The Canaan Dolmite seems to be for the most part a dolomite or dolomitic limestone, with more or less admixed quartz. A white pyroxene or salite is found to be common in it in the vicinity of Canaan, and in the belts extending east and northeast from that point. It has also been found at several localities in the vicinity of Lime Rock, but is only rarely seen west and southwest of that place. Tremolite is also found in this horizon, but as will be more fully explained beyond, this is largely restricted to a zone bordering the Housatonic River on the east. Masses of Canaanite are also found in this horizon, and as neither pyroxene nor tremolite has been found in the Egremont Limestone, their presence here is useful for purposes of identification.

The Riga Schist within this area has the characters which distinguish it on Mount Washington. In most of the ridges where it occurs, garnets alone or garnets and staurolites have been found in it. They are most abundant and of largest dimensions in the ridge south of Twin Lakes Station, the ridge south of Chapinville Station, in Tom's Hill and Mile's Hill, in Mt. Prospect (south of the area here mapped), and in Barnard Mt. and Johnny's Mt.[1] near Sheffield.[2] The mica is often a silvery

[1] These minerals were described from this locality in 1824 by Dr. Chester Dewey. Am. Journ. Sci., Vol. VIII., p. 7.

[2] Professor Dana has specially mentioned them from many of these localities. (l. c., p. 440). The increase in size of garnets and staurolite from Mt. Washington to the Housatonic, as described by him, has not been confirmed by this study. The largest that have been noted are from the south end of the ridge south of Chapinville Station.



GEOLOGICAL MAP OF PORTIONS OF SHEFFIELD, MASS. AND SALISBURY, CT.

One Mile

sericite and considerable graphite is sometimes associated with it.

The Egremont Limestone resembles that found along the east base of Mt. Washington, its principal impurities being muscovite and quartz. It contains locally important layers of calcareous mica schist. In the vicinity of Twin Lakes, two distinct beds of the latter are made out, one immediately below the Everett Schist—a transitional zone—and the other lower down near the middle of the horizon. A third, less important and less constant, zone forms a transition from the Riga Schist to the Egremont Limestone. The upper of these layers forms the cap of Babe's Hill (northeast of Washining Lake). The middle layer is also found in the same hill along the southwest base, and the lowest layer may be seen above the Riga Schist at the first road-corner northeast of Chapinville. Graphitic phases are found as a transitional zone between this horizon and the overlying Everett Schist in the northeastern part of the area, particularly in areas 16 and 25.

The Everett Schist is not chloritic to any marked degree, as is so often the case on Mt. Washington, but is frequently sericitic, usually porphyritic from rounded eyes of feldspar, and frequently passes downward into graphitic schist.

EXPLANATION OF MAP.

The map which accompanies this paper (Plate V.) is based on the Sheffield and Cornwall sheets of the topographical atlas of the United States, by the U. S. Geological Survey, and is drawn on the same scale—1 : 62,500, or one inch to the mile. It overlaps by about one half mile the map which accompanies the Mt. Washington paper. To bring as much of the area as possible on the page, the narrow northern portion is placed in one corner, its actual position being roughly indicated by the positions of the Housatonic Railroad and the large marsh to the west of it. Fig. 5 also extends the map some distance to the south. The area covered by the Egremont Limestone is left blank, while the Riga and Everett Schist areas are shaded, the

former being the darker. The more important of the schist areas have been given numbers from 1 to 38. An attempt has been made to indicate the geological structure on the map by the introduction of such of the important dip observations as the scale of the map will allow, as well as small arrows which indicate the inclination of the trough and crest-lines (pitch). The course of an important fault is traced along the east bank of the Housatonic River.

GEOLOGICAL STRUCTURE OF THE AREA.

Since the beginning of the study of the Green Mountains by the Archean Division of the Survey, Professor Pumpelly has emphasized the necessity of making careful observations of the pitch of flexures, in order to arrive at a complete knowledge of the geological structure. Observations of this character have furnished the key to the structure within the area here studied. The crest lines of the folds show considerable and frequently changing inclinations, but the beds have withstood the stress to which they have been subjected in this direction without dislocation, as there is no evidence of any cross faults. The disturbance which came from the east, and which developed the flexures, has been so great as to overturn most of them, so that their axes dip east, and locally to cause a disruption with the production of rather steep thrusts of small displacement. An important dislocation has occurred along the course of the Housatonic River, which has carried the Canaan Dolomite over the newer beds exposed west of the river.

Structural features as shown in longitudinal sections.—A glance at the map will show that all the important ridges, with the exception of Barack M'Teth, Turnip Rock, and the Bear's Den, are formed of the Riga Schist. The fact that these ridges steadily increase in height in going southward, as well as the tongue-shaped outline of the area, indicates that the general pitch of the flexures is toward the north. This is in perfect accord with the fact that the folds in the main part of the Mt. Washington Mass have a northerly pitch. But although the general pitch within the area now under consideration is north-

erly, the local pitch[1] varies greatly both in degree and direction, and is as frequently southerly as northerly, as indicated by the arrows on the map. At the south base of Tom's Hill the southerly pitch varies from 30° to 50°, and on the road cutting across the north foot of Barack M'Teth, beautiful corrugations in the Everett Schist pitch southward at as steep an angle as 50°. These corrugations are unsymmetrical, the west limbs being the shorter and steeper. The local variations in pitch are strikingly indicated on the map by those ridges of schist which are arranged linearly in the direction of the prevailing strike, being cut off from one another by limestone. The minor changes in pitch are further shown by variations in width of the ridges. Thus we find along the western margin of the area three marked undulations in the crest-line of an anticlinal of Riga Schist trending north-northeast. The northernmost is essentially the double undulation of Horse Hill and area No. 29, then follows the area northeast of Chapinville (14), and the area south of Chapinville Station (10). Fig. 1, which is a longitudinal section along this line, shows besides the three main undulations just mentioned, a number of secondary waves of more or less importance. In Fig. 2 (A) these curves of the crest-line may be better observed. The manner in which this anticlinal ridge disappears near the southern limit of the map is shown in Fig. 1 of Plate VII. The

[1] The pitch at any given locality is determined, either (1) by the direction in which the strike of the two limbs of a fold diverge in a synclinal fold or converge in an anticlinal fold; or (2), by the pitch of the plications in the schist. The harmony in direction and degree of inclination between the pitch of plications and that of the folds of which they are a part, was first suggested by Professor Pumpelly, and proven in the Greylock area. (Cf. T. Nelson Dale, Amer. Geologist, July, 1891).

FIG. 1. Longitudinal section from Horse Hill to Barack M'Teth. Horizontal scale, one inch equals one mile; vertical scale, one-eighth inch equals five hundred feet.

ridge of Riga Schist is seen at A outlined from the surrounding Egremont Limestone by a dotted and dashed line. At B and C are seen Turnip Rock and Barack M'Teth, composed of Everett Schist. Between A and C the average strikes in the limestones are nearly east-west, and the dips (due entirely to pitch) about 30° south. Approaching Turnip Rock the strikes become northerly and the dips easterly, as the limestone mantles around the ridge A.

A second elevated area of the Riga Schist having three principal undulations in the direction of its prevailing strike,

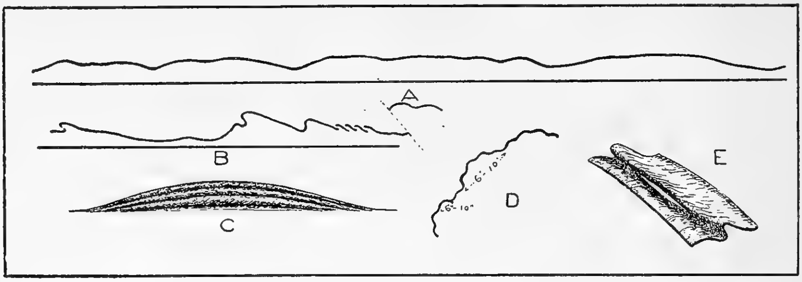
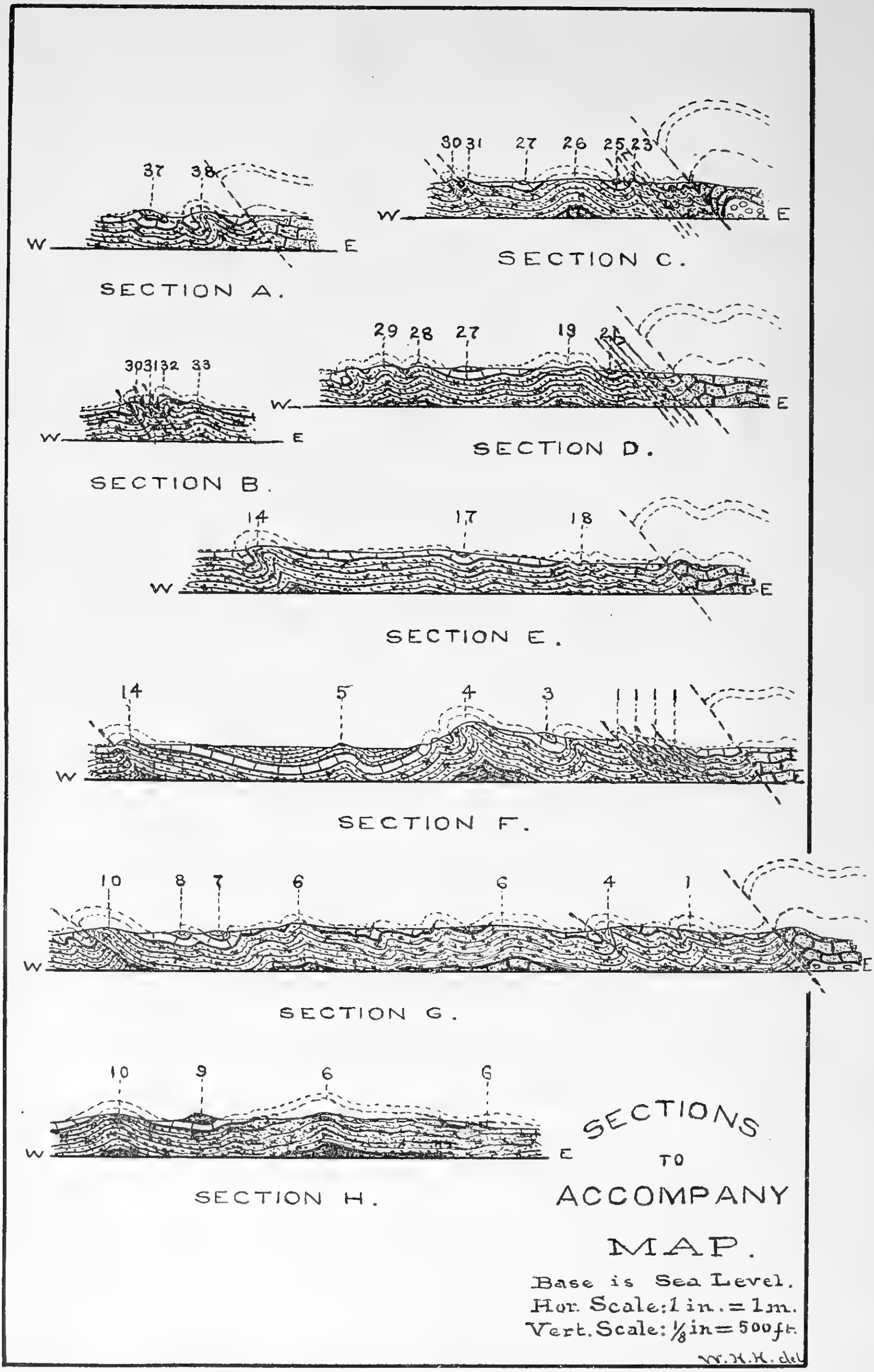


FIG. 2. Diagrams illustrating some of the structural features of the area studied. A, Flexures in crest-line of the western ridge of Riga Schist. B, Flexures in Tom's Hill and region to the west (from section F, Plate VI). C, Diagram showing the corrugated character of some of the smaller schist knolls near Salisbury. D, The same in section. E, Diagram showing the probable manner of development of small steep thrusts in the sharply folded region southeast of Tom's Hill, and in Horse and Peck's Hills.

corresponding with the three undulations of the western schist anticlinal, is traced along the eastern margin of the district. The northern of its three undulations brings to the surface in Peck's Hill, schist areas 26 and 19, and the accessory overturned and ruptured fold of areas 22–24; while the central undulation brings up in Miles Hill and Tom's Hill schist areas 1 and 4, and the southernmost undulation develops the extensive schist areas south of Washining Lake (Area No. 6). The schist of Peck's Hill disappears south of the swamp on the north base of the elevation, but the narrower eastern fold reappears north of the swamp in Johnny's Mount and Barnard Mount, where it, too, soon disap-


SECTION A.
SECTION B.
SECTION C.
SECTION D.
SECTION E.
SECTION F.
SECTION G.
SECTION H.
SECTIONS TO ACCOMPANY MAP.
Base is Sea Level.
Hor. Scale: 1 in. = 1 m.
Vert. Scale: 1/8 in = 500 ft.
W. H. H. del.

pears beneath the limestone as the most northerly outcrop of the Riga Schist. The southern limit of the central crest of the eastern undulation is at the south base of Tom's Hill, where the schist disappears through a southerly pitch varying from 35° to 50°, allowing the Housatonic River to take at this point a south-southwesterly course after being carried to the eastward by the unyielding schist mass of the hill. The minor undulations of the crest-lines of flexures within the northern part of this eastern ridge, are beautifully shown, not only by the areal relations and by divergence of strike observations, but also by the pitch of the plications (cf. arrows on map). Within the central undulation (Miles Hill), the same feature is indicated in the small basins of limestone which are entirely enclosed within the boundaries of the Riga Schist. The triple undulation of the western ridge of the district has a perfect parallel on the east. To the southwest of Tom's Hill just south of Washinee Lake appears an anticlinal of schist, which continues to rise and broaden in going south. The island in the lake is an anticlinal of the Egremont Limestone where it mantles over the ridge of schist. From below the schist anticlinal emerges the Canaan Dolomite near the southern margin of the map. As would be expected, the caps of Everett Schist which are found within the area studied, are widest opposite where the ridges of Riga Schist disappear, *i. e.*, where basins of quaquaversal synclinals are formed by the coincidence of longitudinal and transverse synclinals.

Structural Features as shown in transverse sections.—The nature of the flexuring within the area studied is indicated in the series of sections (cf. Plate VI). The types are the unsymmetrical fold with shorter and steeper western limb, indicating an easterly dipping axis, and the overturned or reversed fold with easterly dipping axis less steep than the first. The western limb of the sharper reversed folds has been ruptured, in some cases producing rather steep thrusts of small displacement. The hade of these faults is about 45°. The main flexures carry also subordinate systems of flexures. The areal geology of Horse Hill and Miles Hill in particular, shows that these properly secondary foldings

are corrugated by a tertiary system of small flexures, and examination of the plications at localities usually reveals even a quarternary system of minor foldings. Many of the small knolls near Salisbury present a surface something like the half of a muskmelon, except that a section, instead of resembling an epicycloid, would be more like a sine curve developed on an arc (cf. Fig. 2 (C). Figure 2 (D) illustrates this structure as seen in the anticlinal ridge No. 6 south of Twin Lakes Station, and in a number of small hills near Salisbury.

The Everett Schist occurs in caps or mantles which are for the most part shallow, nearly symmetrical, synclinals, as exhibited

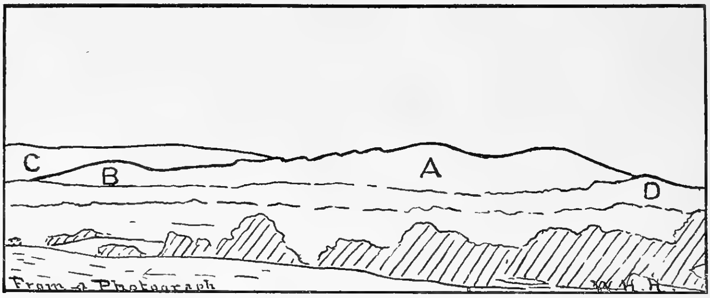


FIG. 3. View of Tom's Hill from the northwest, showing the serrated contour caused by the alternation of belts of schist and limestone. A, Tom's Hill. B, Northeast foot of Miles Hill. C, Canaan Mt. D, Babe's Hill.

in Turnip Rock (9), the cap on the southwest slope of Peck's Hill (27), and the Washining Lake Mantle (5), the latter being a double synclinal, as shown by the anticlinal ridge which forms the island in the lake.

Structure of Tom's Hill.—The doubled-peaked elevation east of Washining Lake is a compound anticlinal of Riga Schist, with two prominent crests appearing in Tom's Hill and Miles Hill respectively. These anticlinals, like most others in this region, are pushed over to the westward. A number of subordinate anticlinals, likewise compressed and overturned and here probably ruptured, are indicated on the map along the northern boundary of the Riga Schist by fingers of schist which protrude

FIG. 1.

FIG. 2.

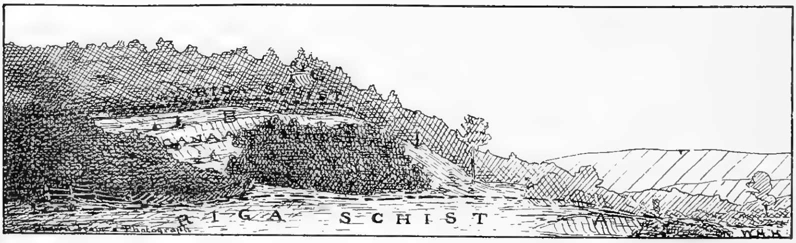


FIG. 3.

into the limestone, as well as by the serrated contour of the ridge when seen from the northwest (cf. Fig. 3). Between Tom's Hill and Miles Hill is a fold of Egremont Limestone overturned to the west and enclosing a core of the Everett Schist. The islands of limestone inclosed in the schist of the eastern flank of Miles Hill, are the result of frequent alternations of pitch in small reversed folds which for a short distance have been ruptured. A stereogram showing the surface of the schist before it had been cut away by erosion would here present the characters of a choppy sea (cf. Fig. 2 E.) These long alternating belts of schist and limestone on the southeast foot of the hill northwest of the railroad bridge (V on map), are indicated topographically by a series of low, sharp ridges which have gradual east and steep west slopes (cf. Plate VII., Fig. 2). Farther south, near the railroad bridge, the several schist ridges become fused together and show more symmetrical undulations. The dips are here uniformly east at angles varying from 30° to 50°, and the closeness with which the belts are crowded together allows insufficient room for the full thickness of the Egremont limestone of this vicinity. The indications therefore are that the folds have here been so sharply compressed that the beds have found relief in a slight dislocation or thrust, producing a structure best illustrated in Fig. 2 (B), to which Suess has applied the term *Schuppenstruktur*,[1] and which I would term *weather-board structure*. It is probable that both the throw and displacement of these dislocations is very slight, being greatest where the crest-lines show an anticlinal structure and least where they show a synclinal structure. An attempt has been made to show the nature of these dislocations as they are supposed to occur on the southeast flank of Miles Hill (Fig. 2 E.) Owing to the covering of earth in the valleys, the course of the fault is not exposed. The only locality where the beginnings of such a

[1] EDUARD SUESS: Das Antlitz der Erde, Vol. I., p. 149.

Gosselet has used *structure ecailleuse* (Ann. soc. geol. du Nord, Vol. XII., 1885, p. 197) for similar structures, and Margerie recommends *structure imbriquée* (Margerie et Heim, Les dislocations de l'ecorce terrestre, Zürich, 1888, p. 82).

fault have been actually observed in the rock exposure, is on the railroad a half mile southeast of the locality just described (S on map). The nature of the flexuring at this point is made

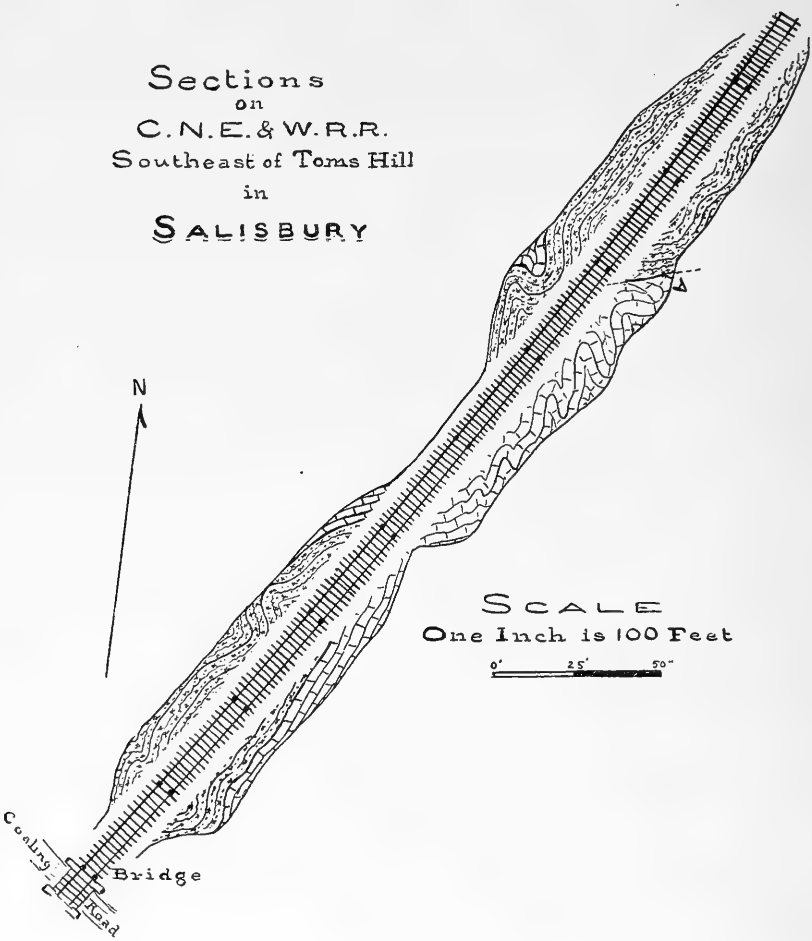


FIG. 4.

clear in Fig. 4, which shows sections in Riga Schist and Egremont Limestone both northwest and southeast of the track, developed on the plane of the track. At the point A, a sharp overturned fold in the limestone shows unconformity with the

underlying schist through a slight fault. The marked difference between the sections north and south of the track is due to steep southerly pitch.

The great Housatonic Fault.—Enough has been presented in the Mt. Washington paper and in the present discussion, to show that the limestone of this region is divisible into two horizons—the Canaan Limestone or Dolomite, lower than the Riga Schist, and the Egremont Limestone above that schist. Additional evidence might be brought forward, if it were necessary, from the region lying to the southward in the vicinity of Limerock. As has also been stated, the Canaan Dolomite, particularly in the vicinity of Canaan and in the valleys east and northeast of there (Monterey, Mill River, Clayton, East Canaan), abounds in crystals of white pyroxene, which has never as yet been found in the Egremont Limestone. Hence this mineral has a certain value for purposes of identification, comparable with that of the garnet and staurolite of the Riga Schist. Masses of Canaanite also occur in it though absent from the Egremont Limestone. Early in this investigation, when the possibility of a differentiation of the limestone was only suspected, this lithological peculiarity was noted, but as the pyroxene-bearing limestone to the eastward did not seem to be separated from the pyroxene-free limestone to the westward by any areal break, the question of divisibility was left open. It was, however, observed that the Housatonic river roughly outlined the westward extension of the pyroxene-Canaanite rock to the north of the interstate boundary. Another striking feature of this line is a ridge more or less pronounced, having its course along the banks of the river. In the southern half it follows the east bank of the river, but crosses it at the small hill called the "Cobble," just northeast of Miles Hill, and to the north of that point borders the west bank.[1] This ridge is composed of a rock which has not been found elsewhere in the region. It is a dolomite abounding in tremolite and containing layers of quartzite and quartzitic dolomite. Par-

[1] The southern portion of this ridge (that east of the river) is the ridge mentioned as Canaanite on page 126 of Percival's report.

ticularly along its west margin the rock is found to be seamed with vein quartz in every direction. These characters have not been found outside of the ridge, which is rarely over a quarter of a mile wide. The well known greenish tremolite of Canaan is from Maltby's Quarry at the extreme south of this ridge. The rock was provisionally designated the tremolitic quartzitic limestone and its area was mapped. Sudden changes in the strike and dip of the beds were found to be particularly common in this ridge.

Now that the stratigraphy has been determined, there seems to be no reason to doubt that this ridge marks the course of a great reversed fault, which in its upthrown limb brings the Canaan Dolomite against the newer beds in its western or underthrown limb. The development of tremolite is ascribed to the profound shearing which has occurred along the fault plane, and the ragged dolomite filled with quartz veins to fracturing or crushing and recementing of the fragments by the silica of waters which have percolated along the fractures—in other words, it is a fault breccia. The ridge has survived as a topographical feature, because of the framework of quartzite and vein quartz and the imbedded crystallized silicates in the dolomite. The fault line may be followed by these characters from near Sheffield village to Maltby's Quarry, northwest of South Canaan, a distance of about ten miles. To the northward it probably connects with some of the faults of Vosburgh Hill, but its course here has not been followed. To the south of Maltby's Quarry the fault is followed in the direction of the prevailing strike to the northeast base of the Cobble,[1] which base it coincides with for some distance. This, as will be more fully shown later when that area is described, is indicated by the Cambrian Quartzite being absent, the actual contact of gneiss and apparently overlying Canaan Dolomite being exposed. On the west base of this narrow hill, the quartzite is present separating the gneiss and dolomite, and it also runs around the north end of the hill to

[1] At South Canaan. This is not the Cobble already referred to and located on the map (Cf. Plate V.)

stop abruptly at the northeast base. The well known white pyroxenes of Canaan come from the dolomite adjacent to the

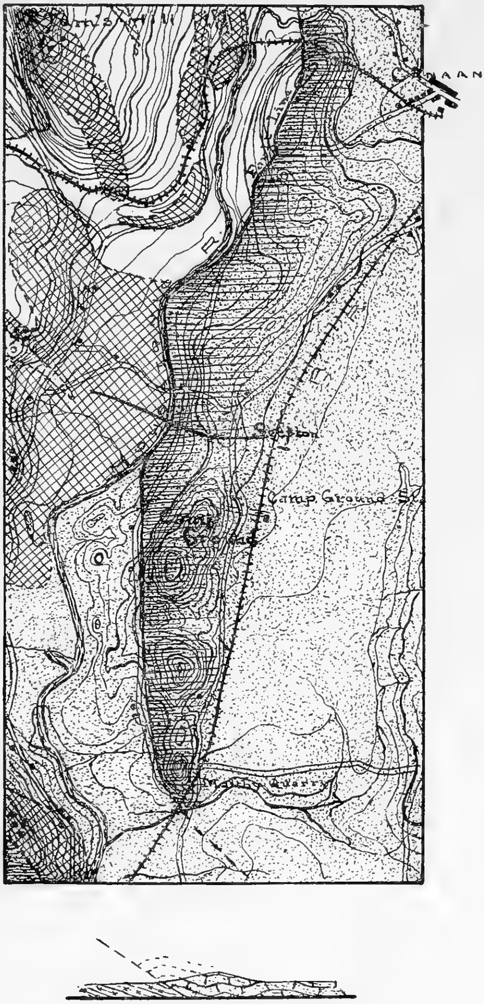


FIG. 5. Map and section of the vicinity of the Housatonic Fault, southwest of Canaan village. Scale and legend the same as in Plate V.

fault line, on the road running immediately at the east base of this hill, and are much the largest that have been found in the

region. The fault probably extends a considerable distance farther to the southward but its course has not yet been traced. The northern course of the fault is indicated on the map.

Starting at the Maltby Quarry, where the surface rock on both sides of the fault line is Canaan Dolomite, and going northward, to the west of the fault line the generally northerly pitch carries the beds lower and lower so that Egremont Limestone is met before Sheffield is reached. On the east, however, no such pitch exists, and Canaan Dolomite is the surface rock for the entire distance. The Riga Schist has not been found in actual outcrop abutting against the fault plane and separating the two calcareous horizons, but this is explained by the absence of outcrops along the river valley. The map and section in Fig. 5 are introduced to indicate how the Riga Schist is believed to meet the dolomite at the fault line. This map is drawn on the same scale and has the same legend as Plate V. An examination of Plate V. will show how the hard Riga Schist of Miles Hill has caused a deflection of the Housatonic River to the eastward in that vicinity. The important easterly deflection which exists in the vicinity of the Canaan Camp Ground (cf. Fig. 5) is believed to be caused in the same way. The low area between the river and the road to the west of this bend is bare of outcrops, but Riga Schist is encountered on the road and covers a considerable area west of it. On the east of the river at this bend the tremolitic Canaan Limestone is encountered almost at the river's bank. There seems, therefore, reason for believing that in this vicinity the fault follows the river and that the two rocks abut against one another at the fault plane.

To the southward of the Maltby Quarry the fault is of a somewhat exceptional character, since the prevailing northerly pitch of the beds to the west of the fault line brings beds lower than the dolomite (First Cambrian Quartzite and then Cambrian Gneiss) to the surface in the Cobble. The upper limb of the fold is no longer the overthrown limb, but it is forced to a lower position. We have here, then, an example of a fault, which at the north is a rather steep overthrust with Canaan Dolomite over

Egremont Limestone, and at the south end a reversed fault with the same rock over Cambrian Gneiss. It follows that the throw varies most widely. At some fulcrum point, which must be near the Maltby Quarry, this is practically *nil.* To the north of that point, the western limb has been downthrown an amount which steadily increases in going north, till in the vicinity of Sheffield it can hardly be much less than a thousand feet. To the southward of the Maltby Quarry, the western limb has been upthrown and the amount of this upthrow at the Cobble must be several hundred feet.

The occurrence of two very thin quartzite lenses, which follow a line parallel with the fault line along "Silver Street" in Sheffield (Cf. Plate V.), is reason to believe that two secondary faults there run parallel to the main fault.

Additional evidence of the main overthrust is the occurrence of numerous very large boulder-like masses of the tremolitic quartzitic dolomite, resting on the Riga Schist to the east of the road on the northeast flank of Miles Hill. It might be argued that they are of glacial origin, since the direction of glacial movement in this section is favorable, but they could only have come from a point just across the river, and such masses are not distributed over the area to the southwest. Such masses are, however, found in abundance along the eastern side of the overthrust for almost its entire length, and it therefore seems most probable that they are fracture blocks produced in the faulting, which have rounded through weathering, and as degradation has gone on, have settled down upon lower beds of the mother rock, and to some extent also upon the Riga Schist west of the river.

This reversed fault presents some analogies with the overthrust faults of the southern Appalachians described by Hayes,[1] and those in New York described by Darton[2], but the fault plane

[1] The Overthrust Faults of the Southern Appalachians, by C. W. HAYES. Bull. Geol. Soc. Am., Vol. 2, pp. 141-154, pls. 2-3. Cf. also Willis and Hayes, Am. Jour. Sci. (3) XLVI, pp. 257-268. Oct., 1893.

[2] On two Overthrusts in New York, by N. H. DARTON. Bull. Geol. Soc. Am., Vol. 4, pp. 436-439.

has here a steeper hade, so that the older dolomite has been carried only a short distance over the newer beds.

Metamorphism along the fault.—Of considerable interest is the recrystallization which has taken place along the fault plane. The tremolite of the Housatonic ridge, and the large pyroxene crystals of the east base of the Cobble at South Canaan, must be explained in this way. The ragged quartzitic dolomite rock which characterizes the Housatonic ridge throughout its entire extent and is not found elsewhere in the region, is believed to owe its characters to a crushing along the fault and a recementing of the fragments by a vein quartz—it is in other words, a fault breccia.

In the vicinity of the great thrust planes of the Northwest Highlands of Scotland, which have been so carefully studied by Geikie, Peach and Horne, and their associates of the Geological Survey of Scotland[1], schistose structure and new minerals have been developed by the shearing, micas, hornblende, actinolite and garnet being produced in this way[2]. Another instance of this sort is furnished by the overthrusts of the Rocky Mountains along the line of the Northern Pacific Railway.[3] These thrusts have likewise produced metamorphism of the beds along the thrust planes, argillaceous layers being made schistose and limestones being whitened and cracked.

Thickness of the Egremont Limestone.—In the Mt. Washington paper, I have shown that the thickness of the Egremont Limestone in the southern portion of the summit plain is less than one hundred feet, and that a little farther south it probably dies out altogether. In the northern portions of that area, where it

[1] The Crystalline Rocks of the Scottish Highlands, by ARCH. GEIKIE, B. N. PEACH, and JOHN HORNE. Nature, Vol. XXXI., pp. 29-35, Nov., 1884.

Report on the Recent Work of the Geological Survey in the Northwest Highlands of Scotland, Based on the Field Notes and Maps of Messrs. B. N. Peach, J. Horne, W. Gunn, C. T. Clough, L. Huxman, and H. M. Cadell. Communicated by A. GEIKIE. Quart. Jour. Geol., Soc., London, Vol. XLIV., pp. 378-441, 1888.

[2] Nature, Vol. XXXI, p. 35.

[3] Report on the Geological Features of a Portion of the Rocky Mountains, by R. G. MCCONNELL. Ann. Rep. Geol. Surv. Canada, (New Series) Vol. II., 1886, p. D34.

attains a greater thickness, no measurements could be made, though it can safely be said that it does not exceed a few hundred feet. The relations made out in the area now under consideration, allow of a thickness which agrees well with that found in Mt. Washington. A locality which illustrates this will be here briefly mentioned, because the structure is so simple as to afford reliable results. The locality is a knoll called Pine Hill, lying at

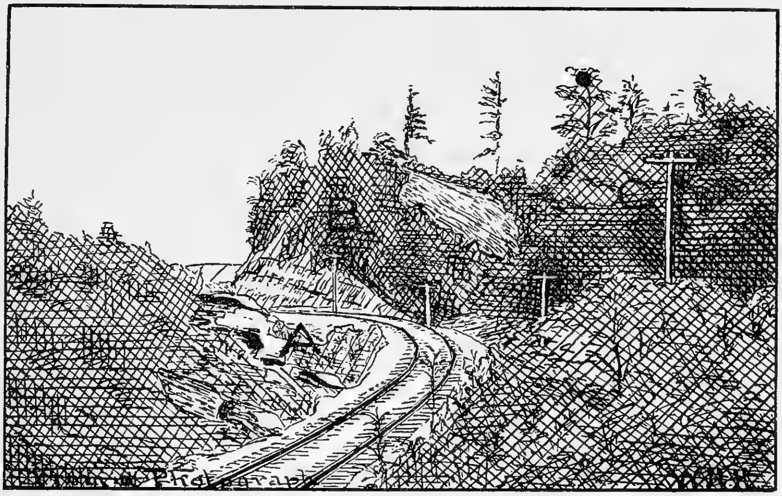


FIG. 6. View of Pine Hill on the southeast flank of Tom's Hill, seen from a point to the west. A, Riga Schist. B, Pine Hill composed of Egremont Limestone. C, Approximate position of cap of Everett Schist.

the southeast foot of Tom's Hill south of the railroad. The dips are low, due entirely to pitch, and the thickness of the limestone less than 100 feet. (This locality is marked P on the map). North of the track (A in Fig. 6) is seen the Riga Schist pitching south at an angle of about 35°. Across the track and a little farther east is Pine Hill (B), composed of a pure, white limestone dipping conformably over the schist, and capped on its south slope by a thin layer of the Everett Schist. The outcrops of this rock are hidden in the view, but their approximate position is shown by C. The thickness of the Riga Schist and the Canaan Dolomite have

not been measured. The former probably has a thickness of much less than a thousand feet. A locality where the Canaan Dolomite appears below it in the core of a fold, is shown in Plate VII., Fig. 3.

Conclusions.—Some of the results of this study may be summed up in the following statements:

I. The district is geologically closely connected with Mt. Washington, and contains the same horizons, viz: Canaan Dolomite, Riga Schist, Egremont Limestone, and Everett Schist. For the most part the same general lithological features characterize these horizons as on Mt. Washington. Pyroxene is a characteristic mineral in the lower but absent from the upper calcareous member. Garnets and staurolites are abundant in the lower but absent from the upper schist member. Locally important beds of calcareous schist occur in the Egremont Limestone. The Everett Schist differs from much of that of Mt. Washington in being essentially non-chloritic. The Egremont Limestone has a thickness of less than 100 feet in the southern part of the area.

II. The tongue-like outline of the area containing schist exposures is due to a general northerly pitch of the flexures to the west of the Housatonic River, though the local pitch of these flexures varies greatly and is as often south as north. Most of the prominent ridges are anticlinals of the Riga Schist, the few areas of Everett Schist being synclinals and largest where basins are formed by a coincidence of longitudinal and transverse synclinals. The schist areas exhibit an arrangement in four[1] east and west belts having each a width of about two miles, as the result of four marked undulations in the crest lines of the flexures. Particularly toward the north these belts are further subdivided by a secondary series of undulations a half mile or more in width, and a tertiary series of yet smaller waves can in some cases be made out at localities. These facts show that the area has been subjected to compression in a north and south direction,

[1] (1) Bear's Den, Barnard Mt., and Johnny's Mt.; (2) Horse Hill, Peck's Hill, etc.; (3) Northern Chapinville area, Tom's Hill, and Miles Hill; (4) Southern Chapinville area, and area No. 6.

as well as in an east and west direction. The compression from the north and south has produced no dislocation, as no transverse faults have been discovered.

III. The rocks of this area have been very sharply folded. The types of folds are the unsymmetrical, with short and steep western and longer eastern limbs, and the overturned and sharply compressed fold with an easterly dipping axis. Reduced and ruptured underthrown limbs are not uncommon, but the evidence is that the extent and the throw of these minor faults is very slight. On the southeast flank of Tom's Hill this has produced the structure which Suess has called *Schuppenstruktur*. I would suggest, as an English equivalent of this term, *weather-board structure*.

IV. An important reversed fault, which has been termed the Housatonic Fault, has a northerly course along the eastern border of the area of schist ridges. Its course very nearly coincides with that of the Housatonic River for a considerable distance. The fault is traced from near Sheffield village to beyond South Canaan, a distance of about twelve miles. North of the Maltby Quarry it has the characters of an overthrust which increases in throw in going north, owing to the northerly pitch of the beds to the west. This has carried the Canaan Dolomite of the eastern or normal limb over the newer Egremont Limestone and Everett Schist of the western reversed limb. South of the Maltby Quarry the western limb has been upthrown, bringing Cambrian Quartzite and Gneiss against the dolomite. The dolomite has been extensively crushed and metamorphosed along the fault plane. Tremolite and white pyroxene have been extensively developed in the vicinity of the fault plane, and vein quartz has cemented the dolomite fragments together, producing a fault breccia.

It is very probable that the rapid alternations of pitch which characterize this area are not altogether unusual. It is only rarely, however, that the areal relations shed so much light upon the form of the crest lines and trough lines of folds. What has been set forth will, I think, show that evidences of general

pitch, to be reliable, must be based on observations made over a considerable area.

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EXPLANATION OF PLATES.

PLATE V.—Geological Map of portions of Sheffield, Mass., and Salisbury, Conn., based on the Sheffield and Cornwall sheets of the Topographical Map of the United States by the U. S. Geological Survey. Scale 1 : 62,500.

PLATE VI.—Series of Geological Sections to accompany Plate V. Their location is indicated on the map (Plate V.) Horizontal Scale: one inch equals one mile. Vertical Scale: one-eighth inch equals five hundred feet.

PLATE VII.—FIG. 1. View showing the southern termination of one of the longitudinal undulations of the western schist anticlinal, as seen from the west. A, Southern limit of a ridge of Riga Schist (No. 10). B, Turnip Rock (Everett Schist). C, Barack M'Teth (Everett Schist). D, Knoll of Riga Schist. E, Tom's Hill in the distance. F, Ridge No. 6 (Riga Schist). The dotted and dashed line shows the approximate boundary between the Riga Schist and the Egremont Limestone, and the dotted line the approximate boundary between the Egremont Limestone and the Everett Schist.

FIG. 2. View of schist ridges separated by belts of limestone at the southeast base of Tom's Hill near the railroad bridge. A, B, C, Schist ridges. D, Slope of Tom's Hill where a fourth schist belt is hidden in the trees.

FIG. 3. Canaan Dolomite occupying the core of an anticlinal of Riga Schist at the south end of area No. 6. The view looks southeast. A, Outcrop of Riga Schist. B, Canaan Dolomite. C, Riga Schist.

THE NEWTONVILLE SAND-PLAIN.

1. *Introduction.*—During the past year the writer has studied the Newtonville (Massachusetts) sand-plain under Professor Davis, of Harvard University, and after studying the deposit as it now exists, made a detailed map of the plain with its feeding esker. Then a model of the region was made in clay on the scale of 1:4000. This clay model was photographed, and is here reproduced in half-tone, in Fig. 1, Newtonville Sand-plain. The conditions of formation were then studied, and a second model constructed, showing a conjectural relation of deposits to the margin of the New England ice-sheet at the time of its formation. A photographic reproduction of this is given in Fig. 2, Ice-sheet Restored.[1]

2. *Making the models.*—The clay was built up in a solid mass to the greatest required height, and the details of form were then cut with graving tools. In making such models it is essential that the foundation for the clay should be firm and not liable to warp. A slate slab, or a piece of heavy plate glass answers the purpose well. While at work on the model it is important to keep the clay moist. So a box lined with rubber cloth should be provided, large enough to cover the clay without touching it, and an inner layer of muslin put in to hold the water. When the model is ready to have a plaster mold made, the edges should be trimmed square, tapering slightly up from the slate so that the mold will slip off easily, the surface oiled, boards placed an inch and a half from the four sides, and liquid plaster poured over it. After the plaster has set, it may be wedged up from the slate or glass, and lifted from the clay. Then the plaster negative should be carefully washed with a brush to remove all oil or clay stick-

[1] Teachers or others who desire copies of models, photographs, or lantern slides can arrange for them by corresponding with the writer.

ing to it, and when hardened with a thin solution of glue and dried it is ready for the taking of a paper positive. This *papier-maché* model is a close representation of the original clay.

3. *A late glacial deposit.*—A glance at the first model will show the typical form of these delta deposits, the esker like an arm, and the sand-plain like a hand with its finger lobes. The esker rises in height as it approaches the head of the plain. The top of the sand-plain slopes very gently downward from the head to the top of the lobes, but the front slopes of the lobes are much steeper, about twenty degrees.

The sand and gravel are so little disturbed that the deposit cannot be pre-glacial. That the deposit was not made by marine or fluviatile action is shown by the three following considerations. First, an aqueous deposit of gravel, composed of fragments from the crystalline high-lands between two and three miles to the north, should have extended originally from its source outward; but the amount of denudation and transportation required to cut out these delta deposits from a continuous sheet extending across the Charles river to the crystalline highlands on the north, whence a large part of the fragments come, would be greater than the post-glacial denudation that has been measured elsewhere. Second, the delta front and the even sloping delta-plain imply standing water, and if this water level existed for so long a time as would be required to form such an extensive deposit, we should expect to find more evidence of its shore line in other localities than now exists. Third, the constructional forms, cusps, hollows, kettle-holes, at the head of the sand-plain are so marked that one cannot believe them to be the product of erosion. The kettle-holes and marshy depressions show that the plateau tops did not extend much farther than at present.

The dwindling New England ice-sheet, whose existence is proved by other facts, supplies all the conditions necessary for the construction of such discontinuous deposits. The ice-sheet could not have advanced over the plain after its deposition, for the sand and gravel would have been easily carried away. There is no gullying of the sides of the sand-plain; therefore it was

FIG. 1.

formed not so very long ago. But the gravel is evidently of glacial origin, being of angular and subangular pebbles, of great variety of material. The conclusion seems inevitable, therefore, that these deltas were formed during the retreat of the ice-sheet.

4. *Stagnant, melting ice.*—In the retreat of the ice-sheet there were parts at least which became too thin to move. As Professor Davis has said:

> During this time it must have melted irregularly, presenting a very uneven, ragged front, from which residual blocks may have been frequently isolated; and it must have endured longest in the valleys, where it was thickest, not only by reason of its greater depth, but also because its surface there, where motion had been fastest and longest maintained, must have been higher than on the hills—this being homologous with the variation in the thickness of a Swiss valley glacier from middle to sides."[1]

It seems to me that we must consider the change to have been gradual from a moving glacier to a stagnant one, and that there may have been times of renewed activity with a forward motion, even in the period of decline. Such forward motion may have had some influence in shifting the course of esker rivers and so have determined where the next sand-plain was to be built. So far as I know, this point has not been worked out in the field.

Crevasses are formed as the ice moves, and change their position according to the tensions in the mass of the glacier. When the tension from motion has ceased, and the ice has become a diminishing, drift-covered mass, the condition represented in Fig. 2, we should not expect to find any crevasses remaining. They would either have been closed by the forward motion of the ice, or would have lost their distinctive character by the excessive melting of their sides, while the water would have washed detritus into them covering the underlying ice, and preventing it from melting as fast as that on either side. Such protection of the ice by detritus must have had great influence in determining the surface forms of the stagnant ice-sheet, as is shown in Professor Russell's account of the sand cones and the deposits in glacial lakelets.

[1] Bull. Geol. Soc. of Am., Vol. I., p. 196.

5. *Comparison of models.*—Turning from Fig. 1, which shows the deposits as they exist to-day, to Fig. 2, which shows the theoretical conditions of formation, it will be seen that the northern half is covered with ice, from which is issuing an esker river. The ice in the second is represented as fitting into the intercuspate hollows shown at the head of the sand-plain in the first model, and is from one hundred to three hundred and fifty feet thick. Toward the rock hills on the east and west it falls off, as would be the case where the ground was higher. The ice has a convex curving surface in front, with contours softened by melting, while on top it is approximately level with here and there surface streams, moulins, and perhaps a little lake.

The three little knobs of older date than the sand-plain standing near its front margin, can be seen in both models. The till-covered hills of bed rock are also the same in the two, but in the second the water stands higher up on their sides. The second model being a trifle larger, a little more of them is shown on the edges. The group of hummocky kames, shown to the southwest of the sand-plain in the first model, is covered in the second by the body of standing water into which the esker river flowed.

6. *Esker river.*—Professor Chamberlin has given us the very helpful distinction between "kame" and "esker" (osar), from the use of the words in Scotland and Ireland respectively. The former is used by the Scotch for their irregular mounds and hillocks, so typically shown in that country, and which, if developed at all in lines, have their axes at right angles to the direction of ice flow; and the latter for the Irish ridges of sand and gravel, beds of former glacial rivers, which have their axes parallel to the lines of motion in the ice. This terminology is here followed.

In the first model the esker, a ridge of sand and gravel, fairly stratified, may be traced from the middle of the northern end, where it is some ten to twenty feet high, curving eastward and then southward again, gently rising to some seventy feet above the alluvial plain shown on the northwest corner of the model of the sand-plain, and one hundred and thirty feet above mean tide.

Then it falls ten feet, and, curving a little to the west, rises thirty feet to where it reaches its greatest elevation, one hundred and fifty feet above mean tide. This is also the elevation of the front of the sand-plain. At this point it breaks up into several more or less clearly defined branches, which distribute the sand to build up the delta in the estuary.

These branches fall off in height towards the head of the sand-plain, as is often seen in similar deposits elsewhere. As it has been shown that the amount of post-glacial erosion has been small, this depression must be due to conditions existing while the ice was present. The first model shows a large kettle now occupied by a pond which lies north of the sand-plain and east of the esker. This depression, being filled with ice after the course of the esker river was changed, must have had an outlet, and as the main body of ice would have prevented the formation of an outlet on the north, it seems reasonable to suppose that this water quietly cut through a slight sag in the esker to the west. This cutting would have continued until the ice-sheet had retreated farther north, and the ice block in the kettle had melted, and its depth would be governed by the amount of the lowering of the water in the estuary, caused by rising of the land.

Two branches from near the north end of the esker run into cusps at the head of a second smaller sand-plain deposit, formed when the ice-front had retreated some two thousand feet, and while the ice remained at this second point there would have been no outlet for the water to the north. The frontal lobes of this second sand-plain are not at all typically developed.

7. *Delta streams.*—In front of the openings of the esker tunnels will be seen the depositing streams breaking up into many branches, as Professor Russell has described them in Alaska[1]. Some of them are represented as having already ceased to flow to the edge of the delta, and are fast filling up; others are pushing out their resulting lobes as far as they can reach; while a third class are supplying detritus to those in front, and are building up their channels to give themselves greater carry-

[1] See Malaspina Glacier, page 238.

FIG. 2.

ing power by increasing their slopes. The front lobes are too strongly shown in the photograph, Fig. 2, as they were left to show the limits of the delta. In the *papier-maché* copies, the water completely covers the slopes of the lobes.

On this deposit, which is 4000 feet from east to west, and 2000 to 3000 feet from north to south, there is only one small kettle-hole. This lack of kettle-holes, so abundant elsewhere, may be taken as an indication that the ice-sheet was comparatively continuous at this time. It evidently became more broken immediately after the course of the esker stream was changed, as there are several kettle-holes to the north of the sand-plain.

8. *Superglacial streams.*—These are represented on the model as smaller than the main channels below, and more inconstant in direction. Their development after the closing up of the crevasses has been made the subject of special study, and its results are shown on the model. Other conceptions of this surface will no doubt occur to many, and any criticism or suggestion will be gladly received. One of the processes that has been a prominent factor in the determination of the form of the surface is that described above, where the detritus in the bed of the stream protects the underlying ice. Little accidents of melting and washing would shift the course of these streams, so that the arrangement of them upon the surface would not be shown by any deposits to-day. As soon as one of these streams found an opening through the ice, a moulin would be formed.

9. *Moulins and kames.*—In the second model I have made moulins in the ice-sheet above the kames in the first model, though I should not like to be understood as affirming that all these kames were surely formed in this way. It is quite probable that further study would show facts pointing to several geneses. Professor Chamberlin says, in speaking of the formation of similar deposits :

" No existing agency, by any extension of its magnitude, is at all competent to account for their localization. The formative agency, or combination of agencies, must have produced, at once, local assortment and local heaping of the assorted material, or, in other words, the assorting waters must have

been confined and concentrated in their derivative action, and likewise constrained so as to heap their material into tumuli, whose location was determined by the constraining agency more than by any feature of the local topography or other present condition."[1]

That some kames are moulin-kames seems to be undoubted, and perhaps we may best picture to our minds their formation by turning an hour-glass and watch the sand heap itself up. A certain amount of stratification will take place in air, which would be increased when the air is replaced by water.

10. *Shore-line.*—With the working hypothesis that this sand-plain was formed in a body of standing water, I reached the conclusion that it was at the head of an estuary. With the existing topography to the south it is almost impossible to conceive of the water as having been enclosed. Such a pond would require too many dams not now existing. If one accepts the delta front as proof of a body of standing water, he seems forced to conclude, on looking over the ground, that the Newtonville sand-plain was built in an arm of the sea. If so, the estuary must have connected with the Atlantic along the present course of the Charles river and through Mother brook to the Neponset. It must have had a very temporary shore-line at any given level, as there is hardly a trace of it now on the till-covered slopes, except in one place on the east bank of the Charles river, about a mile southeast of Newton Upper Falls where Dr. T. W. Harris found a faint cliff, as if made by shore cutting, with a long, gently shelving slope below it. In representing this shore-line on the second model, I have tried to show no beach effect, but to indicate that the land was but recently submerged, and that the water conformed to the contour of the till-covered slopes.

11. *Relation to other sand-plains.*—The intimate connection between the Newtonville sand-plain and the one immediately to the north of it, branches of the same esker running to each, suggests a connection of this bit of the history of our New England ice-sheet with other portions. Were the Auburndale sand-plains formed before or after the Newtonville? What other esker

[1] Am. Jour. of Sci., 1884, p. 381.

rivers emptied into this estuary? When should we expect to find terraces on either side of a sand-plain, as at Pawtucket, R. I.? Why are not sand-plains of more frequent occurrence throughout the area covered by the ice-sheet? These and many other questions are suggested as we study the details of the ice's work. Their answers await the future study and research of those local observers, who will make themselves familiar with the geographic forms of their own regions.

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THE STRUCTURES, ORIGIN, AND NOMENCLATURE OF THE ACID VOLCANIC ROCKS OF SOUTH MOUNTAIN.

THE identification of acid and basic volcanic rocks in the South Mountain, Pennsylvania, has already been announced.[1] This announcement has been further substantiated by detailed petrographical study which it will be the purpose of a later communication to discuss. The present discussion of these rocks will be limited to the acid volcanics, and its object will be; a) to show that the acid volcanics were originally identical with their recent volcanic analogues; b) to further show that their present differences are due to changes subsequent to solidification, chief among which has been devitrification; and c) to propose a name for them that shall express these facts. The structures, which will be described in the course of the paper, will be considered a sufficient guarantee of the igneous origin of the rocks which possess them, without further proof on that point.

Three distinct rock types have been recognized in the South Mountain. (1) A silicious sedimentary formation, represented by a quartzose conglomerate, a sandstone, and a compact quartzite. This is rarely accompanied by an interbedded argillaceous slate. The age of these sediments has been recently determined as lower-Cambrian by Mr. Walcott[2] from the discovery of fossils in the interbedded slates. Underlying these Cambrian sediments, but exposed by erosion for many square miles (150-175), are two types of volcanic rocks, distinctly different in chemical composition but affected by like conditions of con-

[1] G. H. WILLIAMS: The Volcanic Rocks of South Mountain, in Pennsylvania and Maryland. Am. Jour. Sc., XLIV., Dec., 1892, pp. 482-496, pl. I. The Scientific American, Jan. 14, 1893.

[2] C. D. WALCOTT: Notes on the Cambrian Rocks of Pennsylvania and Maryland from the Susquehanna to the Potomac. Am. Jour. Sc., Vol. XLIV., Dec. 1892, p. 481.

solidation and subsequent alterations. (2) In the northern part of the range a brilliantly colored acid volcanic rock predominates. It is porphyritic or non-porphyritic, amygdaloidal or compact. It is accompanied by pyroclastics and breccias. It is sometimes sheared into a fissile slate or sericite schist. (3) Toward the south and extending into Maryland a dark green basic volcanic rock predominates. This is also amygdaloidal or compact, accompanied by pyroclastics or breccias, and usually rendered schistose by pressure.

The acid volcanics.—While some of the acid volcanics are typical quartz-porphyries, others possess a groundmass which, although holocrystalline, contain the evidence of a distinctly different original character. It it this important portion of the acid flow, which will be more particularly treated in what follows. Certain conspicuous structures of the groundmass contain the history of the rock and merit a detailed description.

Fluidal structure.—The fluidal structure, which is a familiar one to all students of rhyolitic lavas, is a marked feature of these pre-Cambrian volcanics. Delicate lines of flow are brought out in great detail by weathering or are painted in brilliant colors in the material washed by the mountain brooks. The microscope shows globulites of magnetite, and hematite, and indefinite opaque microlites following sinuous lines of flow, twisting around the phenocrysts and imparting to them the appearance of eyes.

Micropoikilitic structure.[1]—This name has been given to a structure which is almost universally present in the acid and more rarely in the basic volcanics of the South Mountain. It consists in the presence in the groundmass of irregular quartz areas enclosing micolites of lath-shaped feldspars or other minerals with independent optical orientation. This structure between crossed nicols gives a pronounced mottled or patchy appearance to the groundmass, an appearance which has not infrequently been noted in volcanics of all ages. It has been variously described, usually without being named, in quartz-

[1] G. H. WILLIAMS: On the Use of the Terms Poikilitic and Micropoikilitic in Petrography. Jour. of Geol., Vol. I., No. 2, February–March, 1893, pp. 176–179.

porphyries, felsites, porphrites, peridotites, and rhyolites by numerous writers.[1] This structure was also found in the pre-Cambrian felsite of Georgia,[2] and in felsites of the same age in the neighborhood of Boston,[3] and from Marblehead Neck, Mass.

While the term micropoikilitic is not restricted to a quartz-feldspar intergrowth, in most of the occurrences described these have been the component minerals. In the rocks under discussion the feldspathic material is often so abundant as not to permit of the determination of the mineral character of the host. In such cases, however, a clue to the nature of the cementing material is found in its optical continuity with the porphyritical quartz. The feldspar phenocrysts, on the other hand, do not

[1] R. D. IRVING: Monograph V., U. S. G. S., Copper-bearing Rocks of the Lake Superior Region, pp. 99–100, Pl. XIII., Fig. 13–14, 1883.

G. H. WILLIAMS: Neues Jahrbuch für Min., etc. B. B. II. 1882, S. 607, Pl. XII., Fig. 3. The Peridotites of the Courtland series. Am. Jour. Sc., Vol. XXX., p. 30, Vol. XXXIII., p. 139.

E. HAWORTH: A Contribution to the Archæan Geology of Missouri, Am. Geol., 1888, Vol. I., p. 368, Figs. 1 and 2, Pl. I.

WHITMAN CROSS: On some Eruptive Rocks from Custer Co., Colorado. Proc. Col. Sc. Soc., Vol. II., 1888, pp. 232, 242.

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J. P. IDDINGS: The Eruptive Rocks of Electric Peak and Sepulchre Mountain, Y. N. P. 12th Ann. Rep. U. S. G. S., pp. 589, 646.

WALDEMAR LINDGREN: A Sodalite Syenite and other Rocks from Montana. Am. Jour. Sc. (3), Vol. XLV., April, 1893, p. 287.

J. S. DILLER: Mica-peridotite from Kentucky. Am. Jour. Sc. (3), Vol. XLIV., Oct., 1892, p. 287.

J. J. HARRIS TEALL: British Petrography, 1888, p. 337.

ALFRED HARKER: Bala Volcanic Series of Rocks, pp. 23, 53, 54.

A. C. BRÖGGER: Der Mineralien der Syenitpegmatitgänge der südnorwegischen Augit- und Nephelinsyenit. Groth's Zeitseh. für Krys., etc., Vol. XLV., p. 546.

OTTO NORDENSKJÖLD: Zür Kentniss der s. g. Hälleflinta des Nördostlichen Smalands. Bull. Geo. Ins. Upsala, No. 1, Vol. I., 1893, p. 232.

[2] A section of this felsite, loaned by Professor Pirsson, possesses an interesting and striking resemblance to the South Mountain acid volcanics, and indicates the southward persistence of this rock type.

[3] Thin sections of these felsites were kindly loaned by Mr. Diller. They have many microscopic features in common with the South Mountain rocks, and like them were first referred to a sedimentary origin. J. S. DILLER: Felsites and their associated Rocks north of Boston. Proc. Bos. Soc. Nat. His., Vol. XX., Jan. 21, 1880. Bull. Mus. Comp. Zoöl., Harvard College, whole series Vol. XII., Geol. series Vol. 1.

affect the orientation of the cement. Where the rock is coarser grained, as is the case in some of the basic volcanics, the character of the cement can be directly tested and the material proved to be quartz.

While in some cases this structure is undoubtedly of primary character, as Professor Iddings considers it to be in many porphyrites, in a large class of rocks its secondary origin seems equally plain. Dr. Irving, who very early described this structure in the acid lava flows of the Keweenawan series, thus speaks of its origin.[1] "Whether this secondary quartz may ever be rather a result of devitrification than a truly secondary or alteration-product I have no means of deciding, though it is certainly the latter often, and I should suppose always. It surely can have no connection with the original solidification of the rock." Observations made on the South Mountain rocks likewise point to a secondary origin for these quartz areas. As the origin of the structure is of importance in its bearing on the question of the primary or secondary character of the crystalline groundmass, these observations will be briefly mentioned. In a specimen of basic lava from the railroad tunnel near Monterey the outline of lath-shaped feldspars forming an ophitic structure, which is undoubtedly original, is completely preserved. None of the original constituents of the rock remain, however, unless some of the titaniferous iron oxide is original. The rock consists entirely of quartz, epidote, magnetite (or ilmenite), and leucoxene. The quartz acts as a cement for the other minerals, forming irregular interlocking areas which are quite similar to the micropoikilitic areas of the acid rocks and which produce in polarized light the familiar patchy effects. Fine cracks traversing the rock, and parting the ferro-magnesian phenocrysts (now represented by epidote) are plainly prior to the quartz areas in which they become invisible. There can be no question as to the secondary character of the micropoikilitic structure in this case.

In the acid rocks the quartz areas are frequently more or less oval and outlined by a microfluidal arrangement of globulites,

[1] Opus cit., p. 100.

longulites and trichites of iron oxide. Zirkel figures and describes a similar appearance in the rhyolites of the 40th parallel.[1] He speaks of faint granular lines "which by their fluidal running form a net with a multitude of meshes of oval shape." The meshes are filled by one of two types of crystallization, the micro-felsitic or the spherulitic. The lines suggested to Zirkel perlitic parting. In the ancient lavas of South Mountain the meshes are filled by the micropoikilitic areas or by spherulitic crystallization or by intermediate stages of alteration, that is, spherulites more or less broken up into micropoikilitic areas. In the trichitic spherulites of the modern rhyolites[2] there is an appearance similar to the micropoikilitic mottling, caused by the breaking up of the radiating spherulitic fibers into irregular areas which extinguish differently; just such an intermediate stage between the spherulitic and a completely micropoikilitic crystallization as has been noted in the ancient volcanics. These observations suggest that the micropoikilitic structure represents recrystallized spherulitic growths when it is not the direct results of infiltration and devitrification. In many cases, the crystallization has undoubtedly never been spherulitic, if however, the micropoikilitic structure has been shown to be subsequent to spherulitic crystallization, that is, to the consolidation of the rock in numerous instances in the acid volcanics, selected from widely separated localities in the South Mountain, the presumption favors the secondary origin of the micropoikilitic structure wherever present in these rocks.

Spherulitic structure.—Two sorts of spherulitic crystallization are present in these rocks. They differ in no essential respect but are unlike in appearance. The most numerous spherulites are also the simplest and smallest. They are colorless microscopic spheres, scarcely or not at all perceptible in ordinary light but showing the usual distinct dark cross between nicols. Spheru-

[1] Vol. VI., Geo. Exp. of the 40th parallel, Fig. 1, Pl. VI., Fig. 1, Pl. VIII.

[2] Sections of material from the Rosita Hills, Colorado, and of the Obsidian Cliff, Y. N. P., were kindly loaned the writer for comparative study by Dr. Cross and Professor Iddings.

lites, in every respect similar, have been described and figured by Professor Iddings from the Yellowstone Park rhyolites.[1] While it is not impossible that some of the colorless spherulites are secondary, there is pretty good evidence that many, if not all of them, are primary. These spherulites are embedded in a base which suggests in every way a former glassy condition. In ordinary light there is no appearance of crystallization except the porphyritical. Traversing the groundmass are cracks which occasionally cut directly through a spherulite. Between crossed nicols the field breaks up into a holocrystalline quartz-feldspar mosaic in which the cracks are lost. It seems fair to conclude that the spherulitic crystallization was prior to the cracking, that the granular crystallization is subsequent, and that the cracking took place in an already solidified glass. In these facts we again find obvious indications of a secondary crystallization. In this case the process seems to have been one of devitrification. The other class of spherulites corresponds to those figured by Professor Iddings in Plate XVII.[2] They are much larger than those which have just been described; the smallest being easily discernible by the unaided eye, and the largest about the size of a butternut. Hence they become a conspicuous feature of the rock as exhibited in the field. They are rarely altogether absent, and in some localities are crowded so close together as to constitute the major part of the rock mass. When without regularity of arrangement, and when brought out in relief by weathering, these spherulites give to the rock a superficial resemblance to a conglomerate composed of rounded pebbles of uniform size and shape. The rich greys, blues, purple and red of the spherulites and matrix render this a conspicuous rock.

Spherulites become an even more striking feature of these rocks when arranged in layers such as have been described in the modern rhyolites of the Yellowstone National Park.[3] On a face of the rock normal to the layers, they appear as long

[1] Opus cit., Pl. XVII., p. 276.

[2] Opus cit. p. 277.

[3] IDDINGS: opus cit. p. 276, Pl. XVIII.

parallel bands simulating lines of bedding. Sometimes these bands are 4 m. m. wide, at a nearly uniform distance apart and of an indefinite length. In other cases they are very narrow, dwindling into mere lines and dying out, to be replaced immediately by other lenticular bands. The rock cleaves readily parallel to the planes of these bands, which have become planes of weakness and solution, and the spherulites are entirely replaced by secondary silica. This fact, imparting to the bands an opaque white color, render them the more conspicuous in contrast with the blues or reds of the rock surface.

The spherulites which remain unaltered show in the thin section clear cut, circular, semicircular, and fan-shaped outlines, and are colored purple or red by finely disseminated particles arranged either radially or concentrically in threefold zones. Feldspar phenocrysts often occupy the center of the radial growth. These well preserved spherulites are associated with a groundmass which preserves the characteristics of a glass in great perfection, and which, in ordinary light, could readily be mistaken for a fresh glassy lava. It bears the closest resemblance to the base of some of the Colorado rhyolites. Delicate perlitic parting, which because of its delicacy is usually obliterated, is here preserved in wonderful detail. The presence of innumerable globulites accentuates the perlitic and rhyolitic structures. With crossed nicols the aspect of the groundmass completely alters. All glassy structures disappear, to be replaced by granular quartz and feldspar.

It is impossible by any description to carry the definiteness of conviction as to the original glassy nature of the groundmass which the character of such rock-sections justifies. To one who has studied them in both ordinary and polarized light there can be no question as to the secondary character of the holocrystalline groundmass. One cannot escape the conviction that the rock originally consolidated as a spherulitic perlite, and has become holocrystalline by a process of devitrification.

Associated with a groundmass, whose early glassy condition is not so strongly marked, are the altered spherulites. Their spherical

shape in the hand specimen and their sharply defined outline in the thin section in ordinary light alone testify to their former presence. With crossed nicols these boundaries become inconspicuous, and the field of the microscope shows only a uniform quartz-feldspar mosaic. The crystallization within the spherulitic boundary is sometimes finer grained than that of the groundmass, or the micropoikilitic structure is present in the former when absent from the latter, otherwise the spherulite is in no way distinguished from the groundmass. In the case of the chain spherulites the alteration is complete and universal. There is, in ordinary light, an impressive similarity with the fresh chain spherulites of the Yellowstone Obsidian. The same irregularly scalloped outline, the same central chain of clear spherules. With crossed nicols the close similarity vanishes, for in the ancient rocks the radial growth has utterly disappeared. The clear spherules are composed of finely granular quartz while the sinuous border is not to be distinguished from the quartz-feldspar groundmass.

Axiolitic structure.—Closely related genetically to the chain spherulites, but unlike them in being linearly radial rather than centrally, is the axiolitic formation.[1] These have been described in rhyolites and occur somewhat sparingly in their ancient prototypes of the South Mountain.

Rhyolitic structure.—The sections in which the axiolites were observed possess a holocrystalline character, but exhibit in ordinary light flow and vesicular structures, together with stringers and shreds and curved patches of a brownish red color forming what has been called a rhyolitic structure. This latter structure, which has been figured and described by Rutley,[2] Nordenskjöd,[3] and Vallée-Poussin,[4] and on a macroscopic

[1] ZIRKEL: opus cit. p. 167.

[2] RUTLEY: On the Microscopic Structure of Devitrified Rocks from Beddgelert and Snowden. Q. J. G. S., Vol. XXXVII., 1881, p. 406, Fig. 1-2.

[3] NORDENSKJÖLD: opus cit., p. 5.

[4] VALLÉE-POUSSIN: Les Anciennes Rhyolites dites Eurites de Grand-Manil. Bull. de L'Acad Roy. de Belgique, 3d series, Tome 10, 1885, p. 271.

scale by Irving,[1] is essentially nothing else than a special phase of the fluidal structure, a phase peculiar to flowage in lava consolidating with extreme rapidity, that is, in an acid glass. The granular crystallization has developed with entire disregard to these curved patches, shreds and stringers.

Lithophysal structure.—Often the macroscopic features of the South Mountain acid volcanics disclose their original character more convincingly than does the microscope. Lithophysæ are one of the structures which are best revealed in the hand-specimen, where they are brought out in delicate relief by weathering. The rose-pink petals of the lithophysæ in a paler pink base produce quite as beautiful specimens of this glassy structure as any rhyolite shows. The *micro-pegmatitic structure* shows itself in microscopic pegmatoid groups of phenocrysts such as are found in the Yellowstone rhyolites.[2]

Perlitic parting.—That this structure is occasionally present in the South Mountain rocks in great perfection has already been noted. While its presence is a most reliable test of the former character of the rock, its absence furnishes no evidence against the previous glassy condition of the rock, both because many recent rhyolites show no trace of that structure and because it is most readily effaced by devitrification.

Amygdaloidal structure.—In some localities the acid volcanics are conspicuously amygdaloidal. The bright green amygdules of epidote in a pale pink matrix render this rock strikingly handsome. In a few instances[3] the vesicles, which, as seen under the microscope, are bordered by a broad rim, like the ground-mass in crystallization, but are separated from it by a clear zone of silica and are darkened by an abundance of black iron oxide, bear on the inner edge of this border spherulitic growths. These are surrounded by a clear zone of silica while the center of the vesicle is filled either with an opaque black

[1] IRVING: opus cit., pp. 312-313, Fig. 22.

[2] IDDINGS: opus cit., p. 275, Pl. XV., Fig. 5.

[3] In specimens from Racoon Creek at the east base of Piney Mountain, south of Caledonia Furnace.

oxide or with granular quartz. Crossed nicols show that the spherulites are oriented optically with the surrounding silica, and that the preservation of the radiate structure is due to the arrangement of impurities. The appearance of these vesicles is very like those figured by Professor Cole,[1] who explains their formation by a dual mode of growth—a growth from the groundmass outward converging toward a center, as well as from the center. Whatever may be the facts with reference to the Roche Rosse Obsidians, it is not necessary to call into play an abnormal method of crystallization to explain the phenomena observed in the South Mountain rocks. The spherulites projecting into the vesicles, with their bases sunk into its wall, were recognized by Professor Iddings, who kindly examined the sections, as tridymite spherulites, such as form on the walls of vesicular cavities in all modern lavas.

Taxitic structure.—Still another structure which the South Mountain rocks possess in common with rhyolites is what has been called the taxitic. This consists in the intimate mingling of two portions of the magma, which, from some cause (liquation), are slightly differentiated. The iron constituent, which evidently separated out in the original glass, has been still further crowded into bands and curved lines by the secondary crystallization. The result is the production in some cases of an irregular mottling: *ataxites;* and in other cases of a more or less complex network of interlacing bands following lines of flow: *eutaxites.* This mottling and banding is rendered the more striking by a marked contrast in color. The body of the rock is light gray or pink, and the lines dark blue, gray or red, according as the iron is more or less oxidized. When the iron constituent is arranged in oval or spherical outlines, denoting the former presence of spherulites, the rock may properly be termed a *spherotaxite.*[2]

[1] GRENVILLE A. J. COLE and GERARD W. BUTLER: on the Lithophysæ in the Obsidian of the Roche Rosse, Lipari. Q. J. G. S., Vol. XLVIII., p. 438.

[2] Note sur les Taxites et sur les Roches clastique Volcanique. Bul. de l' Soc. Belge. d'Geo. et Tome V., 1893.

Trichitic structure.—The universal presence of globulites, trichites and microlites of black and red iron oxide, in flow bands, or indifferently distributed, or in concentric zones around spherulites and vesicles is worthy of mention as a further point of resemblance to the modern rhyolite. Such trichites in similar rocks have been described by various petrographers.[1] Such, in brief, is the character of the evidence for the secondary nature of some of the holocrystalline groundmass of the acid volcanics of the South Mountain. It is not easy to present the proof so that it shall carry the weight which justly belongs to it. Very much depends upon effects which it is impossible to reproduce by description, but which carry conviction to the student of these rocks. The contrasting appearance of the sections in ordinary and polarized light cannot be adequately reproduced. The disappearance under crossed nicols of rhyolitic, perlitic, spherulitic, and fluxion structures, so clearly indicated in ordinary light, and their replacement by a homogeneous holocrystalline mosaic is one of the strongest evidences of the secondary character of the crystallization. Nor are there lacking instances where the subsequent nature of the crystallization is in other ways distinctly proven, as in the replacement of radial crystallization by the granular aggregate of quartz and feldspar, which is homogeneous with a granular groundmass, as well as in the character of the micropoikilitic structure. One or more of the structures which have been described are invariably present in the acid volcanics of certain localities. The occurrences, where their structures are absent, show a genetic relationship in the field to typical representatives of the modern rhyolite.

The writer considers that the acid lava flows in South Mountain were, at the time of their consolidation, quite comparable to similar flows as they now appear in the Yellowstone National Park. Certain portions of the flow, as in the case of

[1] S. Allport: On certain ancient divitrified Pitchstones and Perlites from the lower Silurian District of Shropshire. Q. J. G. S., Vol. XXXIII., p. 449.

O. Nordenskjöld: opus cit.

R. D. Irving: opus cit. p. 312.

the Obsidian Cliff, were completely vitreous save for spherulitic and lithophysal crystallization. In other localities the lava was lithoidal, and in the central portion of thick flows holocrystalline. In this way three types of acid volcanics would be developed—rhyolites, lithoidal rhyolites, and quartz porphyries. Every gradation between these types would accompany them. Thus, while there are certain areas in the South Mountain, notably the Bigham Copper Mine and Racoon Creek localities, which exhibit typical ancient rhyolites, other regions display genuine quartz-porphyries. While in the latter rocks, which constitute a large part of the acid volcanics, the groundmass may have been, and probably was, originally holocrystalline, as in some modern lavas; in the case of the former rocks, it is supposed that the groundmass was, at the time of consolidation, wholly or partly glassy. The secondary character of some of the holocrystalline groundmass once conceded, and the indications of an original glassy base recognized, it is easy to suppose that the former was developed from the latter by a process of *devitrification.*

That the process of crystallization does not necessarily cease with the solidification of a rock is well known. That the crystallizing forces are active in a glass as well as in a molten magma has been proven by experiment.[1] This action is exceedingly sluggish, and requires, unless accelerated by heat and moisture, an immense amount of time. Devitrification has been considered the result only of dynamic action.[2] While dynamic action undoubtedly accelerates the process of devitrification, if it does not initiate it, devitrification may also take place independently of dynamic action, as was the case in the famous example of the old cathedral window-glass[3] and the ancient devitrified glass from Nineveh investigated by Sir David Brewster.[4] The nature

[1] DAUBRÉE: Géologie Expérimentale, 1879, p. 158.

[2] VALLÉE-POUSSIN: Les Eurites quartzeuses (rhyolites anciennes) de Nivelles et des Environs. Bull. Acad. Roy. Sc. Lett. et des Beaux Artes de Belg. 56 annue, 3d series, Tome 13, No. 5, 1887, pp. 521–522.

[3] Brit. Assoc. Rep., 1840.

[4] Trans. Roy. Soc. Edin., Vols. XXXII., XXXIII.

of the process is in no way different from the process of crystallization in a fluid magma, save in the rapidity of the action, and is of both a physical and chemical character. It is not the purpose of this paper to discuss the other evidences of metamorphism in the South Mountain rocks. There is ample proof that both dynamic and statical metamorphism were wide spread. While the former would, by shearing, obliterate the original structures of a glassy rock and produce a slate, the latter might be an important initiatory and accelerating factor in the process of devitrification of the glassy rocks.

Nomenclature.—The character of the acid rocks has been briefly presented, and there remains to be considered a name or names which shall be descriptive of them. While the possibility of devitrification can hardly be doubted, the fact that a finely crystalline aggregate of quartz and feldspar may also be the direct product of consolidation from a molten magma is equally recognized by the writer, and to the acid rocks possessing such a groundmass the name quartz-porphryry is given. It is by no means always possible to distinguish between a primary and secondary crystalline groundmass, hence no attempt is made to draw a sharp line between the quartz-porphyries and the devitrified rhyolites.

The typical ancient originally glassy acid volcanic should be distinguished in some way by the name from the typical ancient originally holocrystalline acid volcanic. Is there any name now in use which does this? A great variety of terms has been applied to the acid type of the older volcanic rocks. Under the general group of quartz-porphyries, Rosenbusch classifies them as *microgranites*, with a microgranitic groundmass, *granophyres* with a micropegmatic groundmass, *felsophyres*, with a microfelsitic base, and *vitrophyres* (including pitchstones and pitchstone porphyries), with a vitreous base. Foqué and Lévy use microgranitite, micropegmatite and porphyr petrosiliceux as corresponding terms. By British petrographers these acid rocks have been termed hornstones, claystones, and claystone porphyries, felsites, quartz-felsites, and felsites porphyries, agreeing in this respect

with the older German usage, when they have not followed Rosenbusch. In America both German and English usage has been followed with more or less confusing results. In the nomenclature of the South Mountain rocks an effort has been made to avoid such confusion and to use such a term or terms as shall accurately describe them and all similar rocks. No one of the terms mentioned succeed in doing this. Although, perhaps, most nearly like the felsophyres, these South Mountain rocks cannot be included under that term since they now possess a holocrystalline groundmass.

In so much as many of the English felsites have been shown by Rutley, Allport, Cole, and Bonney to be devitrified obsidians and pitchstones, and thus, like these American rocks, the representatives of the glassy lavas of pre-Tertiary times, these pre-Cambrian lavas of the South Mountain might with some propriety be termed *felsites*. Felsites, however, though useful as a field name may well be objected to as an inaccurate petrographical term. It was originally used to describe an acid base, unresolvable to the naked eye, and at first supposed to be a single mineral.[1] With the introduction of the microscope this macro "felsitic" base was resolved into the microgranitic, micropegmatitic, and microfelsitic groundmass, the point of ignorance being shifted from the felsitic base, macroscopically unresolvable to the microfelsitic base, which is microscopically unresolvable. On the continent felsite has been practically replaced by these terms. British and American petographers have retained it as a field name for rocks formed of this macroscopically unresolvable base without phenocrysts or with inconspicuous phenocrysts. The South Mountain rocks are both without phenocrysts, with inconspicuous phenocrysts, and with abundant and conspicuous phenocrysts. As this irregular distribution of the porphyritical crystals may characterize a single lava flow, it does not seem a sufficient ground for a separation of rock types.

[1] GERHARD: Beiträge zur Geschichte des Weissteins des Felsit und anderer verwandten Arten" Abhandl. der k. Akad. der Wissensch. zu Berlin, 1814–1815. s. 18–26. Naumann Lehrbuch der Geognosie Band 1, 2d ed. 1858, s. 597.

It is very generally recognized that structural features are not conditioned by the geological age of rocks, but are, on the other hand, a function of the conditions of consolidation. That the conditions attending the consolidation of surface flows in pre-Tertiary times do not differ from those attending the consolidation of similar flows in post-Tertiary times has been illustrated by a wide survey of pre-Tertiary and Tertiary rocks on the part of Allport, Judd, Teall and others[1] With this recognition has come the growing conviction among petrographers that mere age should be eliminated as a factor in rock nomenclature.[2] While this is true, it is felt, on the other hand, that there should be some recognition in the rock name of the alteration which the rock has undergone subsequent to its solidification. If, at the time of its solidification, the rock presented the features of a rhyolite, as it is believed much of the South Mountain acid lava did, but since that time has become holocrystalline, both these facts, its original character and its present alteration, should be recognized in the name.

Such a result might be secured by the retention of such well established names as rhyolite, obsidian, trachyte, etc., preceded by a prefix which shall have such a designation as to indicate the altered character of the rock. The prepositions *meta*, *epi* and *apo*, as prefixes, all indicate some sort of an alteration. Their exact force has been thus defined by Professor Gildersleeve: *meta* indicates change of any sort, the nature of the change not specified. This accords with the use of the prefix by Dana in such terms as "metadiorite" and "metadiabase." These terms have been recently revived to designate rocks "now similar in mineralogical

[1]ALLPORT: Address of the Pres. of the Geo. Sec. of the British A. A. A. S., 1873, and many other writings by the same author.

JUDD: On the Gabbros, Dolerites and Basalts of Tertiary Age in Scotland and Ireland. Q. J. G. S., Vol. XLII., 1886, pp.49-97.

TEALL: British Petrography, pp. 64–69.

[2]Reyer, Tietze, Reiser, Reusch (H. H.), and Suess support the statement that age is not a just ground of distinction between eruptive rocks, and Rosenbusch considers that in no very distant future the separation of effusine rocks into an older and a younger series will prove untenable.

composition and structure to certain igneous rocks, but derived by metamorphism from something else."[1] *Epi* signifies the production of one mineral *out of* and *upon* another. This prefix has not been much used. We find it in such terms as epidiorite, epigenetic hornblende and epistilbite. *Apo* may properly be used to indicate the derivation of one rock from another by some specific alteration.

If, therefore, we decide to employ this prefix to indicate the specific alteration known as devitrifiction (*Entglasung*) we may obtain, by compounding it with the name of the corresponding glassy rocks, a set of useful and thoroughly descriptive terms, like *aporhyolite*, *apoperlite*, *apobsidian*, etc., as to whose exact meaning there can be no doubt. In accordance with this usage it is proposed to call all the acid volcanic rocks, whose structures prove them to have once been glassy, *aporhyolites*. While those which have consolidated at a sufficient depth to secure a holocrystalline groundmass should be termed *quartz-porphyries*, whether ancient or modern lavas. The writer realizes that the introduction of a new name into petrographical nomenclature is to be deplored unless it can be shown that the name is formulated in accordance with certain well defined principles. A good rock name should express composition, original structure, and, as far as possible, the process of alteration, if any, that the rock has undergone. It is thought that aporhyolite and the suggested series of similarly formed terms meet these requirements. They are, therefore, adopted as preferable to any in present use.

Paleozoic and pre-Paleozoic acid volcanics have long been studied on the Continent, Although their variation from the modern type of acid volcanic, rather than their resemblance to that type, has for the most part been emphasized by German and French petrographers, there have not been wanting able advocates of devitrification and of an original glassy base for the ancient lavas. R. Ludwig (1861), and Vogalsang[2] (1867)

[1] WHITMAN CROSS: On a Series of Peculiar Schists near Salida, Colorado. Proc. Col. Sc. Soc., 1893, p. 6.

[2] Philos. d. Geologie, 144, 153, 194.

incline to the opinion that the groundmass of certain quartz-prophyries is the result of the devitrification of a glassy lava. The late Dr. K. A. Lossen[1] (1869), on comparing the spherulitic porphyries of the Harz Mountains with the obsidians of Lipari, Mexico and Java, found the resemblance sufficiently striking to lead him to declare that "the porphyry groundmass was originally crystallized as glass, and became cryptocrystalline through molecular rearrangement." Later, Kalkowsky[2] (1874) suggests devitrification through the chemical activity of water, as the process by which the microfelsitic base of certain pitchstones and felsites was developed, and still later H. Otto Lang[3] (1877) described a macroscopically unindividualized base which is similar microscopically to the devitrified base described by Kalkowsky. Sauer (1889) considers the Dobritz porphyries as the final alteration product of a pitchstone. C. Vogel comes to the same conclusion as to the Umstädt porphyries in Hessen.

More recently Klockmann[4] (1890) describes the replacement of the spherulitic crystallization in quartz-porphyries, through secondary processes, by a fine grained aggregate of quartz and feldspar. Osann[5] (1891) describes incipient devitrification in perlite and other glassy rocks from Cabo de Gata. Finally, Link (1892) considers that it is not impossible that the fine grained groundmass of some rocks from America that are closely related to mica-syenite-porphyries, was once glassy or at least partially glassy. Many no less capable observers still hold to an original difference between ancient and recent acid volcanics, and the possibility of devitrification and original similarity is yet an open question in Germany.

[1] Beiträge zur Petrographie der Plutonischen Gestein Abh. der Berliner Akad. 1869, p. 85.

[2] Mikroskopische Untersuchungen von Felsiten und Pechsteinen Sachsens T. M. P. M., 1874, pp. 31–58.

[3] Heinr. OTTO LANG: Grundriss der Gesteinskunde, 1877, p. 43.

[4] F. KLOCKMANN: Die Porphyre der Geol. d. s.g. Magdeburger unferandes m. besonderes Berüsksichtigung d. auftretenden Eruptivgesteine Jahrbuch k. p. Geo. Land. u. Bergakad. zu Berlin, 1890, vol. XI.

[5] Z. Geol. Ges. 691, 716.

In France, La Croix[1] describes andesites from Martinique in which the glass has altered into quartz spherulites and a granular quartz aggregate. It is interesting to note that many of the hälleflinta of Sweden, which, like the South Mountain volcanics, were once described as sedimentary, are proving to be acid volcanics preserving the features of their modern equivalents. Quite recently, glassy and rhyolitic structures in these rocks have been observed and described by Otto Nordenskjöld.[2] In Belgium Vallée-Poussin seems to be the only writer who has brought out the resemblance between the eurites of that country and modern rhyolites. He describes at some length structures similar to those possessed by the aporhyolites of South Mountain. A vacillating state of mind as to the matter of nomenclature is indicated in the titles of his successive papers.[3]

In England the rhyolitic character of the ancient acid volcanics has been recognized and emphasized, and the idea of devitrification is widely accepted. Allport, Cole, Bonney, Rutley and Harker have accomplished most valuable work along this line. Dr. Wadsworth[4] was the first American petrographer to advocate the abandonment of age as a factor in rock classification; while at the same time he recognized devitrification as the process which has been forming felsites out of rhyolites. What he says is of interest in its anticipation of ideas now more generally accepted. "This devitrification gives rise in the older and more altered rhyolites to the feldspar, quartz and microfelsitic

[1] Comptes rendus, CXI., p. 71.

[2] Opus cit.

[3] Les Anciennes Rhyolities dites Eurites de Grand-Manil. Bull. Acad. R. de Belg., 3d series, Tome 10, 1885, pp. 253-315.

Les Eurites quartzeuses (rhyolite anciennes) de Nivelles et des Environs. Bull. Acad. R. des Sc. et des Beaux-Artes de Belg. 56 annue, 3d series, Tome 13, No. 5, 1887.

[4] M. E. Wadsworth: Notes on the Minerology and Petrography of Boston and vicinity. Proc. Boston Soc. Nat. His., vol. XIX., May, 1877, p. 236.

On the Classification of Rocks. Bull. Mus. Comp. Zoöl., Harvard College, vol. V., No. 13, June, 1879, p. 277.

(so-called) base that has so puzzled lithologists in the study of the felsites. The rhyolites of all volcanic rocks preëminently show lamination produced by flowing, a fact which is doubtless due to their being so siliceous. This structure and their devitrification enables us to trace a direct connection between the rhyolites and felsites, which are simply the older and more altered rhyolites. . . . . . . One of the best illustrations of this is to be found on Marblehead Neck, Mass., where at least two distinct flows of felsite occur, one cutting the other. They show the fluidal structure so characteristic of rhyolites,—a character that has been mistaken for lines of sedimentation by geologists. While the enclosed crystals of orthoclase have been taken for pebbles. . . . . . While to the naked eye and under the microscope this rock shows the fluidal structure of a rhyolite, in p. l. it is seen that the base has been completely devitrified, a process that is carried to a great extent in many known modern rhyolites." No other American petrographer has so distinctly advocated the identity of felsites and ancient rhyolites in spite of the fact that many of our felsites illustrate it as unmistakably as do the English felsites. Dr. Irving[1] in his description of the Beaver Bay group of the Keweenaw series repeatedly calls attenattention to the resemblance between the ancient felsites and quartz-porphyries and the modern rhyolites, although he does not express an opinion as to their equivalence. The statement "that the degree of crystallization developed in igneous rocks is mainly dependent upon the conditions of heat and pressure under which the mass has cooled and is independent of geological time" made by Messrs. Hague and Iddings[2] expresses essentially the position of American petrographers on this question.

Apparently in none of the felsites elsewhere described have the varied structures of the modern rhyolite been more perfectly and conspicuously preserved than in the aporhyolites of the South Mountain.

[1] Opus cit., pp. 312, 313, note 5, p. 436.

[2] On the Development of Crystallization in the Igneous Rocks of Washoe, Nevada, with Notes on the Geology of the District, Bul. 17 U. S. G. S. 1885, p. 40.

The subject discussed in this paper forms a part of a thesis, on South Mountain, presented at the Johns Hopkins University. The petrographical study was conducted in the petrographical laboratory of that institution, under the immediate supervision of Professor G. H. Williams, to whose valuable suggestions and stimulating interest the writer is in every way indebted.

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Studies for Students.

GENETIC RELATIONSHIPS AMONG IGNEOUS ROCKS.

It is desirable that the student of igneous rocks should appreciate the fundamental relationships existing between various kinds of igneous or eruptive rocks so far as they are understood at the present time, in order that he may form a proper idea not only of what an igneous rock actually is, but also of the uses and limitations of the terms by which they are designated. So it has been thought desirable to present, in an elementary form, some of the data and opinions bearing upon the genesis of different kinds of rock magmas.

It can be shown that all eruptive rock masses, whether emanating from volcanic vents at the surface of the earth or found enclosed within such vents, or confined to fissures not immediately connected with actual volcanoes, with the exception of certain infrequent occurrences of sandstones, which have been forced, while in a loose and incoherent state, into cracks—it can be shown that all ordinary eruptive masses were in a completely molten or fused condition before solidifying into the rocks they now are, and hence the terms eruptive and igneous are practically synonymous.

The igneous mass or molten magma, as we know by observations at active volcanoes, may obtain a liquidity comparable to that of water,[1] which, of course, would obtain for different temperatures in the case of magmas having different chemical compositions; the less silicious magmas reaching this liquidity at a somewhat lower temperature than the more silicious ones. During the process of cooling, magmas become gradually more

[1] James D. Dana: Characteristics of Volcanoes, etc. New York, 1891, p. 143.

viscous, and crystallization generally takes place, but the two are in a measure independent operations, and the viscosity may be advanced so rapidly that crystallization is more or less completely prevented and glassy rocks result. According to the conditions under which rock magmas cool solidification will be accompanied by more or less complete crystallization. The size also of the crystals will vary with the rate of cooling, and the general texture of the rock will be affected. Different parts of one rock magma may experience different conditions of cooling, and there will result a variety of textures or structures within the mass. It may be that the textural differences are sufficiently pronounced to be given distinctive names, which become the terms by which certain kinds of rocks are designated; for example, granite, porphyry, pearlite, pumice, etc. There is then a relationship between certain kinds of igneous rocks which exists because of different conditions which have attended the solidification of various portions of one body of magma, or of several magmas alike in other respects. The significance of this relationship was long ago appreciated by James D. Dana,[1] who maintained that the textural differences among rocks were mainly due to the physical conditions under which they consolidated; an idea ably advocated and corroborated by Judd,[2] and more recently substantiated by numerous observations in many localities.

Igneous rocks often differ from one another in mineral and chemical composition; in fact, some kinds differ so widely from one another in a mineralogical sense that they possess no mineral in common. And most kinds contain the minerals which may be common to them in quite diverse proportions, and associated with various other species. Chemically they consist of the same essential constituents in variable proportions, the variations being within certain limits. But the proportions are so far from being

[1] United States Exploring Expedition during the years 1838–1842, under the command of Charles Wilkes, U. S. N., 4to. Philadelphia, 1849, Vol. 10, Geology, p. 372 *et seq.*

[2] J. W. JUDD: On the Ancient Volcano of the District of Schemnitz, Hungary. Quart. Jour. Geol. Soc., 8vo, Vol. 32, 1876, p. 292 *et seq.*

fixed for similar kinds of rocks that it would be almost impossible to find two instances in which the proportions between the essential ingredients were exactly the same. The independence of many kinds of igneous rocks might seem at first thought to be clearly established by these mineralogical and chemical divergences. This apparent independence disappears when a great number of rocks are investigated. It is found that few rocks contain the same minerals in any given proportion, and that the variable proportions of minerals produce varieties of rocks which grade insensibly from one extreme of mineral composition into another. Intermediate varieties of rocks which form transitions from one type, or distinct kind, to another have been recognized for many years. But it is becoming more and more evident that the so-called type-rocks are not more abundant in nature than the intermediate forms. It is found that particular kinds of rocks may preponderate in one region and the intermediate varieties be subordinate, but that in other localities the relations may be reversed, and the so-called transitional forms may prevail.

The mineralogical gradation of one kind of rock into another is indicated not only by the comparison of all known varieties of igneous rocks, but more especially by the study of all the occurrences of such rocks in any region where they are abundant. The absence of distinctive types, and the presence of all possible varieties intermediate between the extremes is the most noticeable characteristic. Moreover, the transitional variations are not simply represented by slightly different bodies of rock, but they may often be found to exist within one continuous rock mass. Thus, a large body of rock may change in mineral composition from one spot to another by the most gradual transitions, giving rise to constitutional facies of the main mass. Again, it is found that a large body of rock, which may be nearly homogeneous throughout, exhibits certain mineralogical facies which are like the main portion of some other rock-body in the same region; so that the subordinate variety in one mass is the predominant form in another.

The ability of a rock magma to change in chemical composition in different parts, so as to crystallize into different mineral combinations which correspond to mineralogically diverse rocks, does not appear to be limited to small volumes of magma, but shows itself on quite different scales; sometimes confined to a narrow dike, at others acting throughout a large mass thousands of feet in diameter. That which is seen to have taken place within a comparatively limited volume of molten magma might be reasonably assumed to be possible within much greater volumes. Nevertheless it does not necessarily follow that it has done so; conditions which may have brought about the change in one case may not exist in another.

The probability that such changes have taken place in great reservoirs of molten magma, and have brought about the chemical and mineralogical differences among igneous rocks, finds its support in other evident relationships than those of facies and the gradual transitions in mineral composition between the kinds of rocks. The nature of this evidence is twofold and consists, first, in the existence of associations of various kinds of igneous rocks in volcanic regions; and second, in chemical and mineralogical diversity between different associations of rocks, that is, between groups of rocks belonging to different regions. The association of various kinds of rocks in particular volcanic districts, and their constant recurrence in company with one another in widely distant parts of the world impressed itself upon the minds of Scrope,[1] Darwin[2] and Dana[3] in the first half of the present century, and led them to the opinion that the various kinds of lavas thus associated must have originated from some common source, that is, from a common molten magma, by some process of separation or differentiation.

Subsequently, as the chemical and mineralogical constitution of rocks became more readily determinable, it was discovered that there were chemical and mineralogical characteristics of

[1] G. P. Scrope: Volcanos, 8vo, London, 1825.

[2] Charles Darwin: Volcanic Islands, 8vo, London, 1844.

[3] Loc. cit.

whole groups or associations of rocks which distinguished them from groups in other regions. This was noticed by Judd in studying the volcanic rocks of Hungary and Bohemia, and was afterwards clearly expressed by him in defining *petrographical provinces* as districts "within which the rocks erupted during any particular geological period present certain well-marked peculiarities in mineralogical composition and microscopical structure, serving at once to distinguish them from the rocks belonging to the same general group, which were simultaneously erupted in other petrographical provinces."[1] A striking illustration of the individuality of a petrographical province is found in the unusual group of rocks described by Brögger,[2] from the region of Christiania. They are characterized by a high percentage of sodium and a consequent abundance of alkali minerals. Brögger calls attention to the remarkable fact that the greater part of the rocks in this district are absolutely peculiar to the locality, or nearly so, and have not yet been found in any other part of the world. The association of special kinds of rocks in different localities has also been pointed out by Rosenbusch,[3] and urged as evidence of a genetic relation between the rocks so grouped.

Certain chemical characteristics of special geographical groups of rocks become apparent when all of the chemical analyses are systematically compared and their variations plotted graphically, as has been done by the writer for the rocks of particular localities in the Yellowstone National Park, and for those of Vesuvius and vicinity, and of Pantellaria.[4] It is observed in these cases that the relations of the alkalies to one

[1] J. W. JUDD: On the Gabbros, Dolerites and Basalts of Tertiary Age in Scotland and Ireland. Quart. Jour. Geol. Soc., Vol. 42, p. 54, 1886.

[2] W. C. BRÖGGER: Die Mineralien der Syenitpegmatitgänge der Südnorwegischen augit- und nephelinsyenite. Zeitschr. für Kryst. u. Min., 8vo, Leipzig, 1890, Vol. XVI., p. 83.

[3] H. ROSENBUSCH: Microskopische Physiographie der massigen Gesteine, 8vo, Stuttgart, 1886, pp. ix., 600, 628, 767, 795, 809, 810, 821. Also in Mineral. und petrogr. Mitth. XI., 1890, p. 445.

[4] J. P. IDDINGS: The Origin of Igneous Rocks. Phil. Soc. Washington, Bull. Vol. XII., 8vo, pp. 89–214, Pl. 2. Washington, 1892.

another and to the other constituents is characteristic of the rocks of each group. A genetic relationship is clearly indicated, and it appears that the various rocks in each locality have been derived from a general magma peculiar to the locality.

The distinguishing characteristics of the rocks of different petrographical provinces which may be observed in their chemical composition also find expression in certain mineralogical peculiarities. Thus the presence of a relatively high proportion of potash will insure an abundance of potash-bearing minerals, as at Vesuvius. The relatively high percentage of soda in the rocks of Pantellaria, together with low alumina and relatively high ferric oxide, determines the prevalence of alkali-feldspars rich in soda, and of soda-bearing ferro-aluminous silicates, ænigmatite or cossyrite. The less prominent position of the alkalies in the rocks of Electric Peak and Sepulchre Mountain, and the relatively higher percentages of magnesia and iron oxide leads to the very general presence of orthorhombic pyroxene in these rocks, which is in contrast to the less magnesian and more alkaline rocks of Central France and Germany. The abundance of alkalies and general preponderance of soda in the rocks of the Christiania district expresses itself in the abundance of the alkali-feldspars and feldspathic minerals, and in the prevalence of acmite- and riebecite-molecules in the pyroxenes and amphiboles.

From this it follows that certain rocks belong in particular natural series or groups, and are absent from others, and that two natural series of rocks, when arranged according to the percentages of silica, may grade through similar ranges of silica, but may each embrace different kinds of rocks. Thus:

Silica Percentages.	*Yellowstone Park.*	Silica Percentages.	*Vesuvius and Ischia.*
48–53	Basalt.	46–55	Leucitophyre.
55–62	Pyroxene-andesite. Hornblende-andesite.	55–62	Trachyte.
64–68	Hornblende-mica-andesite. Dacite.		
70–75	Rhyolite.	69–71	Rhyolite.

In such series it happens that rocks bearing the same name differ in certain mineralogical respects, and are really more

closely allied to the chemically nearest variety in their own group than they are to the rock of the same name in another group.

It must not be inferred from the facts just given that every natural group of rocks has some peculiarity which distinguishes it from every other group. There are many natural groups or petrographical provinces, the rocks of which are identical in the minutest detail with those of neighboring or distant regions. And the limits or boundaries of such provinces are not sharply drawn in nature. In some regions the transition from one province to another appears abrupt, in others very gradual. Thus, while certain provinces exhibit distinct mineral and chemical characteristics, others appear to possess characters of several provinces.

Recognizable chemical differences may exist between groups of rocks within less than a hundred miles of one another, and again broad general features may be persistent, or at least may be prevalent, over vast areas of the globe. Within these areas, of course, subordinate variations may exist. The most impressive illustration of this law is furnished by the igneous rocks of the two continents of North and South America. The great belt of Cordilleras and parallel ranges stretching along the western side of North America abound in igneous and volcanic rocks which belong to a quite uniform petrographical province, extending from British Columbia to Mexico and Central America. They are not specially rich in alkalies, and are characterized by a very general presence of the ferro-magnesia mineral, hypersthene; local variations occur. As the eastern portion of this mountain system is approached from the west a gradual increase in alkalies is noticeable, and rocks bearing nepheline, leucite and more frequent alkali-feldspars make their appearance, containing alkali-bearing ferro-magnesian minerals. These have already been described, from Montana, Wyoming, Dakota, Colorado and Texas, and are especially well developed in Arkansas. Similar eruptive rocks have been found in the eastern portion of the continent, in New Jersey, New England and Canada.

In South America the great Cordilleran system of the Andes presents a petrographical province identical, chemically and mineralogically, with those of the North American Cordilleras, and which appears to extend throughout its entire length. In the eastern part of the continent and on the islands off its coast the petrographical province is in turn identical in many respects with the eastern province of North America; the correspondence being most pronounced between the rocks from Brazil, described by Derby[1], and those from Arkansas described by J. Francis Williams.[2]

The chemical and mineralogical qualities or peculiarities which characterize the rocks of particular groups, and at the same time serve to distinguish them from those of some other groups, are like family traits of character, and suggest the intimate relationship and common origin of all of the igneous rocks of the group. They prove conclusively that the varieties of rocks occurring at a particular center of eruption, or in a volcanic district, have been derived from some magma common to the district by a process of differentiation similar to that which has caused smaller bodies of molten magma to become chemically heterogeneous and has produced mineralogical facies.

That the process which has produced the many kinds of igneous rocks in any region, with all their transitions into one another, was a process of differentiation of an originally homogeneous magma, and not the compounding of two or more different ones, is shown by the geological relationships between the various bodies of rock belonging to a volcanic center; more especially the order in which they have been erupted. A process dependent upon any set of physical conditions, which continues active for long periods of time must yield results that are to a very considerable extent functions of time, that is, they must be

[1] O. A. DERBY: On Nepheline Rocks in Brazil, with special reference to the Association of Phonolite and Foyaite. Quart. Jour. Geol. Soc. 8vo, London, Aug., 1887. Also The Tingua Mass. *Ibid.*, May, 1891.

[2] J. FRANCIS WILLIAMS: The Igneous Rocks of Arkansas. Annual Report of the Geological Survey of Arkansas for 1890. Little Rock, 1891.

accumulative. Hence, if the process is one of synthesis or commingling, the mixture should be the more complete the longer the process has been in operation. On the other hand, if the process is one of differentiation the separation should be the more perfect as time goes on. The various bodies of rock occurring in a large volcanic region have been erupted at widely different times, and while belonging to a connected period of volcanic activity may often represent the lapse of ages. Their genetic relationship has been the result of some active principle coëxtensive with this vast time, and persistent or intermittent; the effect in either case must be accumulative.

It is found in all regions carefully investigated that there is a sequence in the eruption of different varieties of rocks which is most characteristic. From the nature of the causes leading to the extrusion of volcanic lavas, the irregularities of the conduits through which they reach the surface and the probable diversity in the physical conditions obtaining in different regions, it is to be expected that the course of events will not be the same in all cases, or constant in any one instance. Hence the sequence of rocks will not be uniform for all regions, nor will it necessarily be simple in any case. The sequence discovered by von Richthofen,[1] when expressed in general terms, is of very wide application, and is to the effect that the earliest eruptions are of rocks having an average or intermediate composition, and that subsequent eruptions bring to the surface magmas of more and more diverse composition; the last eruptions producing the most diverse forms. The transition from a magma of intermediate composition to those of extremely divergent composition, is clearly the result of a process of differentiation. "This correspondence between the petrographical and the geological succession," as Brögger[2] remarks, "appears to prove conclusively a genetic connection between successive eruptions." The same conviction has been expressed by Geikie, Teall and others. Evidences of the mixing

[1] F. von RICHTHOFEN: The Natural System of Volcanic Rocks, 4to. San Francisco, 1868.

[2] Loc. cit. p. 83.

of different rock magmas to form an intermediate modification are exceedingly local, and appear to be confined to narrow limits along the junction of one body of rock with another.

The genetic relationship between the various kinds of igneous rocks belonging to a center of volcanic activity, which is plainly indicated by their chemical, mineralogical and geological relationships, is in the nature of a generic connection. They have originated from some common magma or parent stock, and to a very large extent are characterized by whatever distinguishing peculiarity was characteristic of the parent magma. They are in this sense consanguineous. The presumably homogeneous parent magma has become heterogeneous by some chemico-physical process or processes, so that different portions of it have different chemical constitutions. The differentiation undoubtedly takes place according to fixed laws and within limitations affected by the original constitution of the magma, and by the external controlling conditions or agencies. Further than this we shall not venture in the present article. It will be sufficient to consider some of the consequences of the general principles of magmatic differentiation.

First. If differentiation is controlled by external agencies or conditions, such as changes of temperature and pressure, which depend largely on the environment of the magma, then the results of differentiation should vary when the external conditions vary. It is not to be expected, therefore, that similar magmas will always yield the same results when differentiated, within certain limits. They may have experienced quite different physical conditions. The more uniform the conditions the more concordant the results.

Second. Since the process of differentiation requires time, is progressive, and, from geological evidence already alluded to, often continues for ages, it follows that eruptions from a reservoir, where the process of differentiation is taking place, will draw off magma whose constitution will depend on the phase of differentiation attained by the parent magma. The phase will naturally depend on the time at which the eruption takes place.

Moreover, since the process of differentiation necessitates the coëxistence of differently constituted derived magmas in various parts of the parent body or reservoir, the kind of magma drawn off at an eruption will also depend upon the portion of the reservoir drawn from.

Third. If, in a given region of eruptive rocks, each body of rock was the immediate solidification of the magma drawn directly from one common reservoir, they would represent the phases of differentiation in the parent magma at the time when the eruptions took place. If, however, the magma drawn from the reservoir did not solidify immediately, but remained in a molten condition within the fissure or conduit, a still further differentiation within this derived magma might take place under conditions imposed by its new environment. In this manner differentiation might proceed at quite different rates and possibly with diverse results in the parent magma and in the derived magma. Material, then, which, through subsequent eruption, might come to a place where it could solidify, might be derived from the parent magma or from the derived magma, and would represent different phases of differentiation. Either set of conditions of eruption may exist in nature, and much more complex ones. The first may very well be found in great fissure eruptions such as have taken place in western America. The second are probably represented by groups of volcanic vents. Both are simply modifications of eruptive processes, and differ in no essential respect.

The genetic relationship of rocks belonging to one center of eruption, or to one group of centers, or to one petographical province, makes plain the fortuitous character of so-called rock types; the constitution of any rock mass depending primarily upon the phase of differentiation, and on the portion of the reservoir let out. It proves the fundamental character of the variability in composition of such rocks, both as between different bodies of rock and also within the mass of one continuous body in many cases. The degree of homogeneity in a rock body will depend upon the relation of its volume to that of the reservoir

from which it was drawn, and the conditions of differentiation existing there, and, further, upon whether it has undergone subsequent differentiation within itself.

The textural variations which were discussed in the first part of this paper, and which may exist in diverse portions of one rock body, or in different bodies of similar magmas, add still further to the complexities in solidified magmas. Rock magmas are thus known to vary frequently in chemical composition, mineral composition and texture. Names of rocks which are defined in terms of these three characters, can only apply to that portion of a rock body exhibiting the characters specified. Other parts of the mass will have different names, and to this extent be different rocks. The student should therefore recognize the difference in the idea conveyed by the term *rocks* as ordinarily used, and that which is involved in the expression *rock-body*, as a geological unit.

JOSEPH P. IDDINGS.

Editorials.

The December *Forum* contains an interesting article by Dr. D. G. Brinton on "The Beginning of Man and the Age of the Race." It affords, incidentally, several suggestions of value to geologists who are concerned in working out the problems which relate to the fossil relics of man on this continent. Dr. Brinton reasons that we have good grounds for locating man's birthplace only where mammals that are very near to him in physical prowess and mental aptitude are known to have existed some fifty or one hundred thousand years ago. This, he thinks, "at once excludes a large portion of the earth's surface, as the Arctic, Antarctic, and colder temperate zones, the lofty plateaus of the world and its inclement shores." "The whole of America must be excluded, for it shows no signs of having been the home of the higher mammals, that is, apes or monkeys without tails and with thirty-two teeth." By similar exclusions, the area of probable origin of man is limited to Southern Asia, Southern Europe, and Northern Africa. A fuller exposition of Dr. Brinton's views was given in his address before the American Association for the Advancement of Science at Madison iast August.

Without giving unqualified assent to all the limitations urged by Dr. Brinton, it would appear from the distribution of types kindred to man in the Pliocene and Pleistocene periods, and from the fact that the evolution of a naked animal from the hairy one can reasonably be supposed to have taken place only in a very warm climate, that primitive man, in the strict and proper sense of the term, can scarcely be supposed to have been an inhabitant of America. It is difficult to see how he could have reached this continent while in his strictly primitive state by land migration (even if there were land connection in the Behring region)

without traversing extensive cold and mountainous tracts quite prohibitory to a strictly primitive naked man of tropical origin, unless such transit were made in the early part of the Tertiary era before the development of cold northern climates and before the erection of the modern mountain systems. The early Tertiary, however, was an era of submergence rather than of elevation and land connection, and the possibility of such migration is extremely doubtful. Primitive man cannot well be supposed to have gained access to America by water until he had learned the art of navigation, or, in other words, until he had reached a somewhat advanced state of civilization. The strong presumption is, therefore, that man came to America only after he had attained to a stage of development much beyond the primitive one. It would appear that he must have become possessed of the power of protecting himself from the vicissitudes of climate and of securing the means of living under adverse conditions, or else had acquired the arts of navigation to an extent that would permit him to cross from the one continent to the other in warm latitudes.

As man's full evolution did not, therefore, probably take place on this continent, a complete series of relics of that evolution cannot be looked for here. Hence a system of interpretation of fossil relics which is based upon a theory of complete evolution here or which presumes the existence here of a complete series of relics does not carry inherent force, but rather the contrary. It is more probable that the oldest fossil relics of man on this continent represent, not a primitive, but some advanced stage of evolution. There is no inherent reason for expecting to find "paleolithic" or any other very primitive stage of culture here, however well demonstrated that stage may be on the eastern continent. To establish the existence of that stage here, unquestionable geological evidence, strong in itself and quite independent of theoretical support, must be produced. The geological problem in America will be greatly clarified when it is recognized that its solution must rest on strict stratigraphical and palæontological grounds, and not on any parallelism with a

theoretical evolution applicable only to the land of man's origin. The present stage of civilization is certainly not an immediate derivative of the next preceding, but has been imposed upon it unconformably, so to speak, and disjunctively. It is intrusive or superposed, and not derivative. So it is probable that the peculiar phases of the higher civilizations found in Central and South America were intrusive and not derivative. It is, therefore, not improbable that the entire succession of civilizations on the American continent consists of a series of intrusions or superpositions from the west and from the east, overlapping each other unconformably and disjunctively. They can, therefore, be worked out safely upon no theory of genetic succession. Each factor must be determined by means of its own inherent evidence.

T. C. C.

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PROFESSOR JAMES D. DANA has a short article in the November number of the *American Journal of Science*[1] touching upon the recent discussion of the divisibility of the glacial period, in which he draws forth generalizations on two important lines, viz., (1) the personal attitude of writers on the subject, and (2) the difference between the glacial phenomena of New England and of the upper Mississippi basin. These seem to us to lie in the right direction, in the main, but in both cases to have somewhat missed the truest lines of distinction and to have fallen short of the most significant features. Professor Dana draws attention to the divergent views of New England and of western glacialists, and concludes that there must be some difference in the phenomena of the two regions to account for the differences of view. This seems to us very true and very important. The difference in the phenomena is, however, we think much more radical, and, at the same time, much more simple than that suggested by Professor Dana. It is, to our view, simply this: In New England only the latest epoch of the glacial period is distinctly repre-

[1] New England and the Upper Mississippi Basin in the Glacial Period. Am. Jour. Sci. III., Vol. XLVI., No. 275, Nov., 1893, pp. 327–330.

sented. The earlier episodes (to use a term not in controversy) may have representatives there in overridden and buried deposits, but, if so, they are obscure and have not been distinctly delineated. In the West, on the other hand, a very considerable series of episodes is well displayed. These embrace not only those presented in New England, but a considerable series of earlier ones not at all (distinctly) represented there. These greatly prolong and diversify the glacial series. In our judgment, it is not simply a doubling of that of New England, but a much higher multiplication. The whole series cannot, therefore, be judged by the incomplete New England representatives. All investigators, we think, or nearly all, agree that the New England glacial deposits fall within a relatively brief epoch and are not much (at least not very distinctly) differentiated. We agree heartily with those who would refer the declared New England drift to one epoch (reserving opinion, of course, regarding remnants of overridden or obscure drift of earlier episodes). New England is little better fitted to be a standard for the interpretation of the whole glacial series than it is for the whole Palæozoic series. In neither case is the series fully and distinctly represented, nor in either case is it typical. This is implied significantly in the relative state of delineation of the formations in the eastern and western sections. With a great preponderance of workers and of skill, no historical divisions of the glacial formations have yet been traced entirely across New England, not even those of an episodal rank. In the interior, on the other hand, something like a score of historical stages have been delineated over broad areas. Lines of episodal delimitation aggregating many thousands of miles have been mapped. Any attempt, therefore, to revise the work of the interior by the phenomena of New England is not likely to be more successful than the revision of the Palæozoic series on a like basis.

In classifying personal opinions, a dividing line separating the New England and the western workers is valuable and significant. But a much more significant cleavage plane, we think, may be found between those glacialists who have studied the

later episodes (or the earlier episodes) exclusively and those who have studied *both*. To have studied the Hudson River beds, east and west, is an inadequate preparation for deciding whether they are to be placed in a separate epoch from the Trenton beds or not. Both the Hudson River beds and the Trenton beds should be studied in regions where both are well displayed. So of the drift deposits. Classified on the basis of the *formational* distribution of critical studies, the true generalization falls easily into form, viz., those who have studied the formations of one epoch believe in one epoch; those who have studied the formations of more than one epoch, believe in more than one epoch.

The special individual opinion upon which Professor Dana lays stress ceases to have significance, or rather has its significance reversed, when it is observed that the studies on which it is based (most admirable in extent and in quality) fall almost exclusively within zones referred, by common consent, to a single, late, relatively brief glacial epoch.

Respecting the reference of the differences between the drift of the east and of the west to meteorological causes there is room here only for inviting attention to the pregnant fact that the greatest southward extension of the drift is found where the present meteorological and topographical conditions are least favorable. The drift of the interior reaches south of 38° latitude, that of New England only a little south of 41°, a difference that equals about three-fourths of the extent of New England in latitude, exclusive of Maine. The inferiority of the drift of New England in extent, in massiveness, and in serial development is the feature that calls for explanation in adverse conditions rather than the magnificent deployment of the glacial series on the plains of the interior.

T. C. C.

Reviews.

Recent Contributions to the Subject of Dynamometamorphism from the Alps.

A. Heim: Geologie der Hochalpen zwischen Reuss und Rhein. Beiträge zur geologischen Karte der Schweiz, Vol. XXV., 4°: Bern, 1891, pp. 503.

C. Schmidt: Beiträge zur Kenntniss der auftretenden Gesteine. ib. Anhang, pp. 76.

L. Milch: Beiträge zur Kenntniss des Verrucano. Erster Theil : Leipzig, 1892, pp. 145.

M. P. Termier: Etude sur la Constitution géologique du Massif de la Vanoise. Bull. des Services de la Carte géol. de France. No. 20, Paris, 1891, pp. 147.

For many years both Huttonian (metamorphic) and Wernerian (original deposition) principles have been advanced to explain the crystalline schists of the Alps, as well as those of other regions. Because of their youth these great mountains are in many ways peculiarly fitted to throw light upon the difficult problems presented by these rocks. Many of the most classic Alpine localities are now being investigated by modern methods and are yielding welcome results which tend to establish not merely the fact, but also the nature, cause and processes of metamorphism.

Nowhere is this more true than in the region of vast earth-movements which Professor Heim of Zurich, has made the scene of his life work. As the result of his labors in this field, he was able to publish in 1878 his monograph on the Tödi-Windgälle group and the accompanying essay on the Mechanism of Mountain-making—a work which must certainly be regarded as epoch-making in suggesting the clue to a satisfactory explanation of the problems of regional metamorphism. This book Professor Heim now supplements with another of almost equal size, which contains the explanatory and descriptive text of the remainder of Sheet XIV of the Geological Survey of Switz-

erland. This map, which was published on a scale of 1 : 100,000 in 1885, embraces the area between the St. Gotthard railway and the Rhein, north of the great central (Tessin) massif which forms the south flank of the Alps. Hence it includes the eastern portion of the Aar and Gotthard massifs, with all the younger formations in their most disturbed and implicated development. The thirteen years which have elapsed since the appearance of the earlier work have so greatly multiplied observations and stimulated thought that the standpoint regarding the whole subject of dynamic metamorphism is seen to be far advanced. Nor has Professor Heim himself been instrumental in any small way in bringing about this result. Aside from his own detailed field work, his suggestions as to the efficacy of orographic movement as a metamorphosing agent have been of profound and world-wide influence. Hence we cannot be surprised that he should have inspired enthusiastic students within the limits of his own special field. Others have worked out under his direction many details upon which some of his own broadest and most far-reaching generalizations rest. Some of the best of these results appear almost simultaneously with his latest work and form an integral portion of it. This is notably true of the special petrographic studies of both the eruptive and sedimentary rocks of two important and much discussed horizons—the Bündnerschiefer and the Verrucano—in both of which the processes of dynamometamorphism can be made out clearly and precisely followed.

More than one quarter of the Swiss atlas sheet XIV is occupied by that diversified complex of phyllites and schists, called by Heim the *Bündnerschiefer*. Their stratigraphical relations are, on account of the dislocations to which they have been subjected, often very obscure. They have been variously interpreted by different observers, but as the result of years of mature observation Professor Heim gives a full presentation of the facts, and now concludes that he must differ with Bonney, Gümbel, Diener and others who have ascribed to them a greater age, and agree with A. Escher v. d. Linth, Theobold and Rolle who regard them as a united and continuous series belonging in the main to the Lias. Toward the east, where these schists have their broadest and least disturbed development, they are comparatively little altered, and consist of calcareous shales and phyllites, impure limestones, sandstones, dolomitic and gypseous beds, interstratified with green schists and serpentine which are shown by microscopical exam-

ination to be altered volcanic material in conformable layers. Farther west, where these same rocks become tightly compressed between the gneisses of the central massifs, they have become recrystallized in proportion to the amount of their dislocation. "The study of the Bündnerschiefer," says Heim, "was that which years ago first convinced me of the possibility and reality of crystalline metamorphism being produced without the agency of eruptive contact, since I here for the first time observed how a belemnitiferous calcareous argillite became gradually more and more crystalline by the development of such minerals as mica, garnet, hornblende, zoisite, etc., at first as indistinct and imperfect nodules, and later as good crystals" (l. c., p. 52). The Bündnerschiefer, both in their less altered localities and in occasional beds, which have been by chance saved from metamorphism, are quite rich in Jurassic fossils.

About one-half of Professor C. Schmidt's appendix to Professor Heim's monograph is devoted to the petrographical description of the Bündnerschiefer, while the remainder treats of the crystalline rocks of the Aar, Gotthard and Adula massifs. A few preliminary remarks on the melaphyre of the Kärpfstock supplement the author's earlier communications with reference to the eruptives occurring in the Glarner double-fold.[1] The rocks from the three crystalline massifs are mainly the characteristic Alpine gneiss-granites or protogine, with dioritic or amphibolitic interpositions. Sericite- ottrelite- paragonite- zoisite- glaucophane-schists and eclogites also occur. The Adula gneiss is characterized by a green potash-mica (phengite) which is both uniaxial and biaxial. The rocks of the *Bündnerschiefer* are described by Schmidt under two principal heads: *a*) gray and black schists which are more or less completely metamorphosed sediments; and *b*), green schists which are foliated and metamorphosed eruptive material. Under the first division are mentioned schists with newly crystallized chloritoid, zoisite, tourmaline, epidote, biotite, muscovite, quartz, plagioclase and rutile. In some cases complete pseudomorphs of zoisite after echinoid remains are to be found. Other more tightly compressed beds at Nufenen, Val Piora, Lukmanier, Scopi, Ariolo, and other localities are still more highly crystalline, containing disthene, garnet, staurolite and similar minerals in abundance. These rocks have also been petrographically studied by Prof. U. Grubenmann.[2]

[1] Neues Jahrbuch für Min., etc., Beil. Bd. IV., p. 288, 1886. Ib., 1887, I., p. 58.

[2] Mitth. Thurgauischen Naturf. Gesellsch., Heft. VIII., 1888.

The second division or green schists include foliated gabbro, diabase, variolite, serpentine and various pyroclastic deposits now filled with new epidote, uralite, chlorite, saussurite and other secondary products. They show many points of analogy with the greenstone schist areas of the Marquette and Menominee districts on Lake Superior. Of more than usual interest are Schmidt's descriptions of the chloritic ferruginous oölite of Callovien. This was once a glauconitic oölite of Jurassic age, whose spherical particles have, by dynamometamorphism, been flattened, while their iron has crystallized as magnetite and hematite, and their glauconite changed to chlorite. The process of metamorphism in the Bündnerschists is summed up by Schmidt as follows: "The first stage of the metamorphism of the sediments always consists in the development of rutile microliths, as well as isolated and usually skeleton crystals whose nature depends on the composition of the metamorphosed material. These new phenocrysts gradually increase both in number and size; they are always filled with abundant inclusions of the groundmass whose sedimentary arrangement is not destroyed within the newly formed phenocryst. Finally, the clastic groundmass is transformed into an aggregate of crystalline minerals; and, where the metamorphism is most intense, the contrast between new phenocrysts and groundmass is least distinct." (l. c., p. 71.)

As a result of both his own and Schmidt's work, Heim concludes (l. c. p. 488): 1) that all the demonstrable orographic disturbance, and hence all the dynamometamorphism within his area, is post-Eocene, and much of it post-Miocene; 2) that two sorts of metamorphism must be distinguished. The recent dynamic metamorphism which was caused by, and hence was synchronous with orographic movement; and the much more ancient and probably still continuous metamorphism due to heat, moisture, and simple pressure without motion, which he calls *diagenetic* metamorphism (statical metamorphism of Judd). He contrasts the effects of mechanical metamorphism upon highly crystalline and sedimentary rocks, in that the same cause crushes the former into a finely granular schistose series, and recrystallizes the latter by developing large phenocrysts within them. He attributes these results in his particular Alpine region entirely to dynamic action, since he can find no trace of eruptive material which could have produced contact metamorphism in rocks of tertiary age.

The regret expressed by Professor Heim at the time of writing his text that no one had been found to thoroughly investigate the dynamic phenomena of the Verrucano seems about to be removed by the work now being published by Dr. L. Milch of Breslau. He has recently offered as his *habilitationschrift* the first part of his petrographical study of the Verrucano rocks of Graubünden, which deals with the historical development of the knowledge of this formation and the dynamic metamorphism of the eruptive rocks occurring in it. The second part, to be published later, will treat of the metamorphosed sediments and chemical aspects of the whole subject. The basic carboniferous eruptives of the region investigated are all melaphyres belonging to the three types: olivine-weisselbergite, navite and tholeiite; in other words old basalts. Some of them are well preserved, and show clearly the progressive effects of metamorphism with increasing mechanical disturbance. Some of the rocks are massive and others amygdaloidal, but the effect of the pressure is finally to destroy all of their original characters and to produce from them chloritic, epidotic, sericitic, or carbonate schists, which could just as well have originated from sediments of the proper composition. The mechanical action differentiates the originally homogeneous rock into portions of very different mineralogical composition, which in the most squeezed parts of a fold form fine parallel layers, but in the less compressed areas are intimately interlaced. Thus the same orographic force, while it may produce the same result from rocks genetically very distinct, can also, on the other hand, produce highly diverse rocks from one and the same mass.

The acid Carboniferous eruptives of the area studied are quartz-porphyries, or old rhyolites. Some of these form an important part of the pebbles in the Verrucano conglomerates, while others occur *in situ* as a contemporaneous part of this formation. The latter rocks show many points of resemblance with the Windgälle porphyries, considered by Heim and Schmidt (N. J. B. BB. IV., 1886) as pre-Carboniferous. Milch distinguishes two categories of metamorphic changes exhibited by these acid eruptives. The first is mainly *mechanical*, consisting of crushing and granulation, and producing fine-grained, jaspery schists; the second is mainly *chemical*, producing sericite from the feldspathic constituents which forms interlacing membranes. There is then here observable a complementary relation between the mechanical and chemical work of dynamometamorphism,

like that pointed out by the present writer in the greenstone-schists and associated rocks of Lake Superior. (Bull. U. S. Geol. Surv., No. 62).

Professor Termier of the Ecole des Mines at Saint-Etienne has given in his essay on the constitution of the Vanois massif in Savoy, another excellent contribution to our knowledge of the effects of orographic movement in metamorphosing Alpine sediments of Caboniferous and Triassic age. This is all the more welcome from France where dynamometamorphism has been rather slow to gain recognition, in spite even of the convicting demonstrations by Gosselet in the Ardennes. The *schistes lustrés*, which bound the Vanois massiv on the east, considered by Lory as upper Triassic, are made by Termier pre-Carboniferous. The principal horizons which have been studied with reference to metamorphism are the Permian and Trias. The former is represented mainly by quartzites and phyllites, altered and recrystallized in proportion to the disturbance they have suffered. In the phyllites rutile, sphene, tourmaline, garnet, zoisite, epidote, glaucophane, chloritoid, various micas and feldspars, and quartz have been abundantly developed. Many interesting details and figures are given to illustrate the development of these new minerals. Albite crystals by their growth in the phyllite have sometimes displaced all, or only a part of the original schist constituents, while in other cases they have not disturbed their position at all. Various minerals are traced in their gradual development from indistinct nodules to perfect crystals. Only the metamorphism of sedimentary beds is considered, and the general conclusion is reached that their alteration is independent of eruptive action, and entirely conditioned by the heat produced by orographic movements. This heat is supposed to have been very gradually produced and very slowly dissipated. The author thinks that a temperature of 200 to 250 C., continued through ages, would suffice to crystallize new compounds like feldspar, quartz, carbonates, tourmaline, chlorite, micas, ilmenite, rutile, etc., without affecting the bulk composition of the rock. In exceptional cases an intenser movement might give a temperature of 300 C., sufficient to produce amphibole, which will appear as glaucophane, if, as in his Permian beds, the original sediments are very rich in soda.

George H. Williams.

Text Book of Geology: By SIR ARCHIBALD GEIKIE, F.R.S. Third edition, revised and enlarged. Pp. i-xvi, 1147.

The preface to the third edition of this standard text-book states that it has been entirely revised and in some portions recast and re-written, so as to bring it abreast of the continuous advance of geological science.

A careful comparison of the third edition with the second indicates that this claim is fully warranted. The general plan of the volume is unchanged, but there are few discussions in which modifications do not appear. In many places the changes consist of nothing more than the addition or modification of a sentence or a paragraph. Even these minor modifications and additions are of great value, since in them are embodied many of the newer facts and ideas which recent research has developed. Thus we find the newer estimates of the average elevation of the continents; new suggestions concerning the age of the earth; the introduction of new descriptions of minerals of petrographical importance, and the modification of some upon which new light has been thrown by recent investigations; the adoption of Rosenbusch's terms for certain rock structures; the use of the word megascopic in place of macroscopic; a re-arrangement of rocks upon a genetic basis, as sedimentary, massive or eruptive, and schistose or metamorphic, and a better subdivision under these heads; throughout the descriptions of rocks, additions and improvements incorporating the more essential facts brought out in recent publications. The possibility of the metamorphic origin of some granites is minimized, and the probability that the greater number of them are eruptive is emphasized; the processes of metamorphism are elaborated, and the kinds of mineralization of common occurrence are pointed out. We find, too, new facts as to the amplitude of earthquake waves; the results of the more recent mathematical calculations concerning the distortions of the sea level by the attractive influence of land elevations; fuller statements as to the possibility of changes of sea level, and concerning the causes of oscillations of the level of land and sea; the conclusions to which experiment has led concerning the effect of hot water on the fusion temperature of rock; new ideas concerning the flow of rock as the result of crushing and pressure; clear cut statements growing out of recent discussions concerning the efficiency of glacial erosion; a multitude of facts at one point and another drawn from the reports of the Challenger, and from the reports of other deep

sea exploring expeditions, as to sedimentation far out from land; the results of recent biological investigation touching the supply of lime carbonate and silica from which animals and plants secure materials for their shells; a more explicit statement than the earlier edition contained concerning the complexity of the glacial period; a modification of the classification of geological formations of North America, incorporating the ideas of the correlation essays of the United States Geological Survey, etc., etc. The additions and changes concerning these topics fairly represent the character of the alterations to be found throughout the volume. These new touches are sufficiently numerous and suggestive to make the volume valuable, even to those already in possession of the earlier edition.

At a number of points the changes have been much more considerable. Thus twelve pages were devoted to the discussion of the Archean in the old edition, while thirty-seven pages are given to the pre-Cambrian in the new. The general character of the changes at this point were foreshadowed in an article by Sir Archibald in the first number of this journal. Two groups of pre-Cambrian rocks are distinctly recognized, the lower consisting of gneisses and schists, and the other of the pre-Cambrian sedimentaries and volcanics. The character, the relations, and the genesis of these groups is briefly but comprehensively set forth. Concerning the first group the conclusion reached, as expressed in the author's own words, is as follows:

"These rocks are in the main various forms of original eruptive material, ranging from highly acid to highly basic; they form in general a complex mass belonging to successive periods of extrusion; some of their coarse structures are probably due to a process of segregation in still fluid or mobile, probably molten, material consolidating below the surface; their granulitized and schistose characters, and their folded and crumpled structures point to subsequent intense crushing and deformation; their apparent alternation with limestone and other rocks, which are probably of sedimentary origin, are deceptive, indicating no real continuity of formation, but pointing to the intrusive nature of the gneiss."

Concerning the second group of pre-Cambrian rocks, the sedimentary and volcanic series, Sir. Archibald takes the same position as in the article already referred to[1] and essentially the same position as that of Prof. Van Hise, already set forth in this journal[2] and elsewhere.[3]

[1] This Journal, Vol. I., p. 1.

[2] Vol. I., No. 2, p. 123.

[3] Bulletin 86, United States Geological Survey.

The adoption of any general terminology for the pre-Cambrian rocks is deprecated. In the author's judgment, "the term Laurentian cannot henceforth have more than a local significance." He further indicates his belief that "there will be much less impediment to the progress of investigation by the multiplication of local names than by the attempt to force indentifications for which there is no satisfactory basis. Each country will have its own terminology for pre-Cambrian formations, until some way is discovered of correlating these formations in different parts of the globe." The great duration of the time interval represented by the pre-Cambrian sedimentaries and their great unconformities is distinctly recognized. Much fuller details are given in this than in any earlier edition, concerning the development of the pre-Cambrian in different parts of the world. On the whole, the chapter on pre-Cambrian is much more satisfactory than in any other existing text-book. Several other periods are much more fully dealt with in this edition. This is especially true of the Silurian and Tertiary. Various new figures of fossils are introduced, representing important species of recent discovery.

In the section dealing with glacial geology, we notice that no distinction is made between the formations known in America as kames and osars, and are a little surprised to find the statement concerning kames (osars as we know them in America) that "no very satisfactory statement of their mode of origin has yet been given." Perhaps this may be true in a restricted sense, since there is much discussion as to the exact character of the streams which produce them, but that the formations which we have come to call osars were produced chiefly by superglacial or subglacial streams, does not seem to admit of serious question, so far as America is concerned. We are also surprised to find the loess placed in the recent or post-glacial series. This is not the correct reference of most of the loess in the United States, for at various points along the northern border of the very extensive loess covered area, as in Illinois and Iowa, the loess is frequently found beneath the till of the later ice invasions. The eolian theory of the origin of the loess is favored. This seems to be by far the most satisfactory theory for the Asiatic loess, and is finding much favor in connection with the loess of Europe. It is doubtless the loess of these countries to which reference is especially made. But the points urged in support of the eolian theory are not all applicable to the American formation. For example, "the thoroughly oxidized condition" of the iron content of the loess

cannot be urged in support of its eolian origin on this side of the Atlantic. Where the loess of the United States is typically developed, and has any considerable thickness, its iron content is not often thoroughly oxidized below a depth of four to six feet. The same is true of the loess of some parts of Germany. So, too, it may be much more troublesome to account for the presence of even a few aquatic shells in an eolian deposit, than for the presence of many land shells in a water deposit. The frequent inter-stratification of loess and sand at the base of the formation, the occasional presence in the loess of stone quite beyond the power of wind to transport, its general habit of following river courses, the presence of aquatic shells, and its lack of oxidation and leeching except for a short distance from the surface, are considerations of sufficient weight to make it very doubtful if the larger part of the American loess can be due to the wind. On the other hand, we believe that some (quantitatively a small part) of the loess of the United States is unquestionably of eolian origin. It has long seemed possible to the writer that formations may have been grouped together under this name which have had very different origins at very different times. This notion is emphasized in the volume before us, where the adobe of the United States, two or three thousand feet thick, is referred to as the loess, though this is not the formation commonly known as loess, and can hardly be one with it in origin. Many new facts are given concerning glaciation in regions where the work of the ice has not, until recently, been known.

The incorporation of the great body of new facts and suggestions throughout the volume has meant the digestion of a large body of recent literature. Indeed, there appears to have been very little geological literature produced since the earlier edition of the work of which the author has not made use, and to which we do not find explicit reference in the new edition.

ROLLIN D. SALISBURY.

Bodengestaltende Wirkungen der Eiszeit. Vortrag von DR. AUG. BÖHM, *Privatdocent an der k. k. technischen Hochschule,* Vienna.

The difficulty of finding satisfactory summaries of the physical features of European countries makes such essays as the above especially welcome to the American student, particularly if he contemplates a trip abroad. The essay is one of a series of lectures, published by

the *Verein zur Verbreitung naturwissenschaftlicher Kenntnisse* in Vienna, now in its thirty-third year. The essays may be had separately, and a table of contents of the thirty odd volumes may be procured from the publisher, Hölzel, for a nominal price ; from this one may select such numbers as he wishes. Recent volumes contain articles by Suess, *Ueber die Structur Europas*, from which the geological traveler may gain a breadth of view that will greatly profit him ; by Penk,[1] on *Das Oesterreichische Alpenvorland*, and *Die Donau* (Danube), from which more local views may be gathered of equal value in closer studies. Dr. Böhm's essay is a well-argued presentation of the belief that even the greater Swiss lakes, as well as nearly all the smaller ones, are the result of glacial erosion. He justly emphasizes the moderate proportion of depth to length in even the deepest of the marginal lakes ; and the location of these lakes with respect to the greater glacier which formerly emerged from the Alpine valleys on the Piedmont districts. Even in those valleys where no marginal lakes now exist, as in the valleys of the Lech, Inn, Salzach, and others, rivers emerging from the north-eastern Alps, there have recently been lakes, but their basins are now filled and drained by the active streams that traverse them. The high level lakes, held in rock basins and enclosed by mountain cirques (Karen), are with even more confidence ascribed to glacial action. Many of the smaller lakes have been extinguished already since the glacial period. In the Tyrol, no less than 118 lakes recorded on the maps of the last century, are now drained. In this relation, the Alpine valleys seemed to have advanced further towards recovery from the glacial accident to which they have been subjected than the Norwegian streams ; for in Norway, many a river is still only a string of lakes. It is notable that drumlins are not mentioned by Dr. Böhm as characteristic products of glacial action ; hence we must infer that they are seldom seen in Continental Europe.

WM. M. DAVIS.

Analytical Abstracts of Current Literature.

Conditions of Appalachian Faulting. By Bailey Willis and C. Willard Hayes. (Amer. Jour. of Sci. Vol. XLVI., pp. 257–269).

The cross section of a great mass of sediments accumulated over a zone parallel to the shore is that of a bi-convex lense. One edge rests against the shore from which the mass at first thickens rapidly and then thins gradually seaward. A broad shallow trough is thus formed by the deeper strata which may be called an original syncline. The authors give data to show that previous to compression such original synclines of deposition existed in the paleozoic strata of the Appalachians in Pennsylvania, east Tennessee, northwest Georgia, Alabama and in other localities.

In the original synclines of the Appalachian province the steeper seaward dip was northwestward and the gentler shoreward dip was southeastward. If strata in such a position be subjected to sufficient compressive force, the original syncline will be exaggerated and the steeper shorter arm will be rotated as between the forces of a couple. If compression is continuous long enough the beds may be overturned.

From this stepfold a thrust-fault may develop in either of three ways. The pressure tending to exaggerate the fold is most efficiently transmitted by the most massive stratum, and any condition which weakens this stratum may lead to a fault. The three conditions under which this massive stratum may be weakened are erosion, fracture, plastic flow; the second being the most common in the Appalachian region, where the massive stratum seems to have fractured, forming thrusting faults under loads of 2,800 to 11,000 pounds per square inch, but to have folded without breaking under loads of 11,000 to 34,000 pounds per square inch.

The authors discuss with the aid of diagrams the mechanics of repeated parallel folds, and show that the parallel folds are later than that located by the original syncline, and are consequent each upon the next preceding it in time and position. In the Appalachians the compressing force was directed both northwestward and southeastward. But when folding began there was a movement from the force towards the resistance. This the authors conceive to have been a superficial flow of a broad zone from northwest to southeast, from the sea towards the land. H. B. K.

Ueber Geröll-Thonschiefer glacialen Ursprungs in Kulm des Frankenwaldes. By ERNST KALKOWSKY in Jena (Zeitschrift der Deutschen geologischen Gessellschaft. XLV. Band. 1. Heft. Januar, Febuar und Marz, 1893, pp. 69–86.)

In the midst of the shales and greywackes of the Upper Kulm of Frankenwald, there is a peculiar sort of conglomerate (*geröll-thonschiefer*). This conglomerate is exposed at but few points. It is not certain that all the exposures belong to one horizon, though nothing is known which forbids this conclusion. The demarkation of the conglomerate from the underlying and overlying beds is sometimes, but not always, distinct. The conglomerate has a known thickness at one point of at least 18 m. It is wholly unstratified, and is made up of something like equal parts of clayey matter, and well-rounded stones (*geröllen*). The sand grains are conspicuously angular, while the larger stones are as distinctly well-rounded. In no case do the sandy or stony materials show any traces of arrangement suggestive of stratification. The stony material varies in size from pebbles to small boulders, the largest being $22 \times 29 \times 12$ c. m. In connection with these limitations in size it must be remembered that the exposures are very limited. While it is difficult to determine the origin of the stony material in all cases, it does not seem necessary to suppose that it is of very distant origin. The author considers the various possibilities concerning the origin of this conglomerate, and concludes that it is the work of rivers which were affected by floating ice. The conglomerate is therefore an indication of cold climate in the adjacent regions at the time of its formation. The author thinks that the Carboniferous ice period, belief in which seems not to be without foundation, may be brought into connection with the cold climate indicated by this conglomerate bed in the upper Kulm. He further thinks that the cold climate of the Kulm may have made itself felt over wide areas, since more or less extensive conglomerate beds of this age occur in widely separated parts of the German Empire.

R. D. S.

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(*Further acknowledgments of pamphlets already received will be made in the next number.*)

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